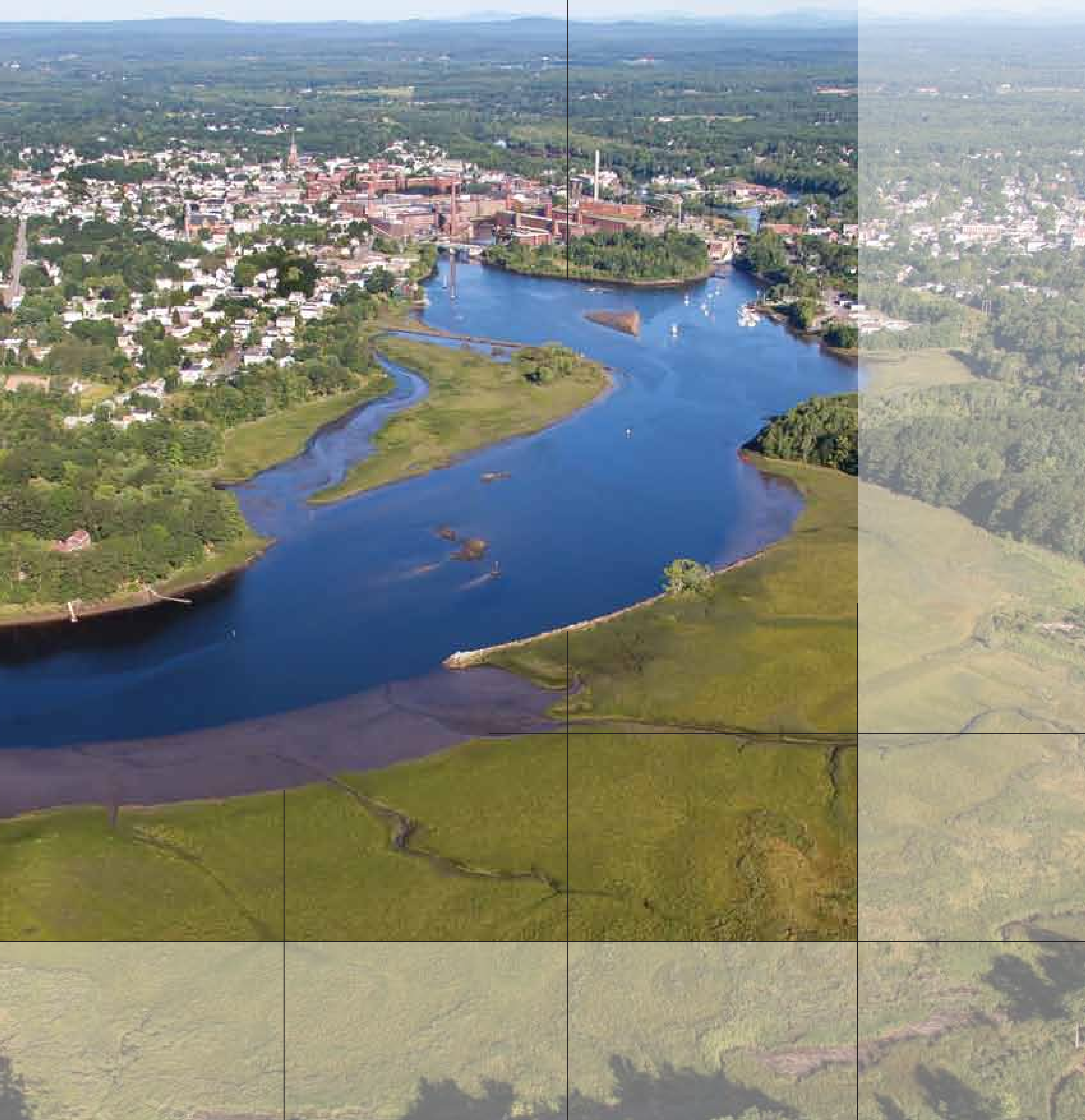
Sustaining the Saco estuary

final report 2015



Sustaining the Saco
estuary

final report 2015

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Report Editing and Design: Waterview Consulting

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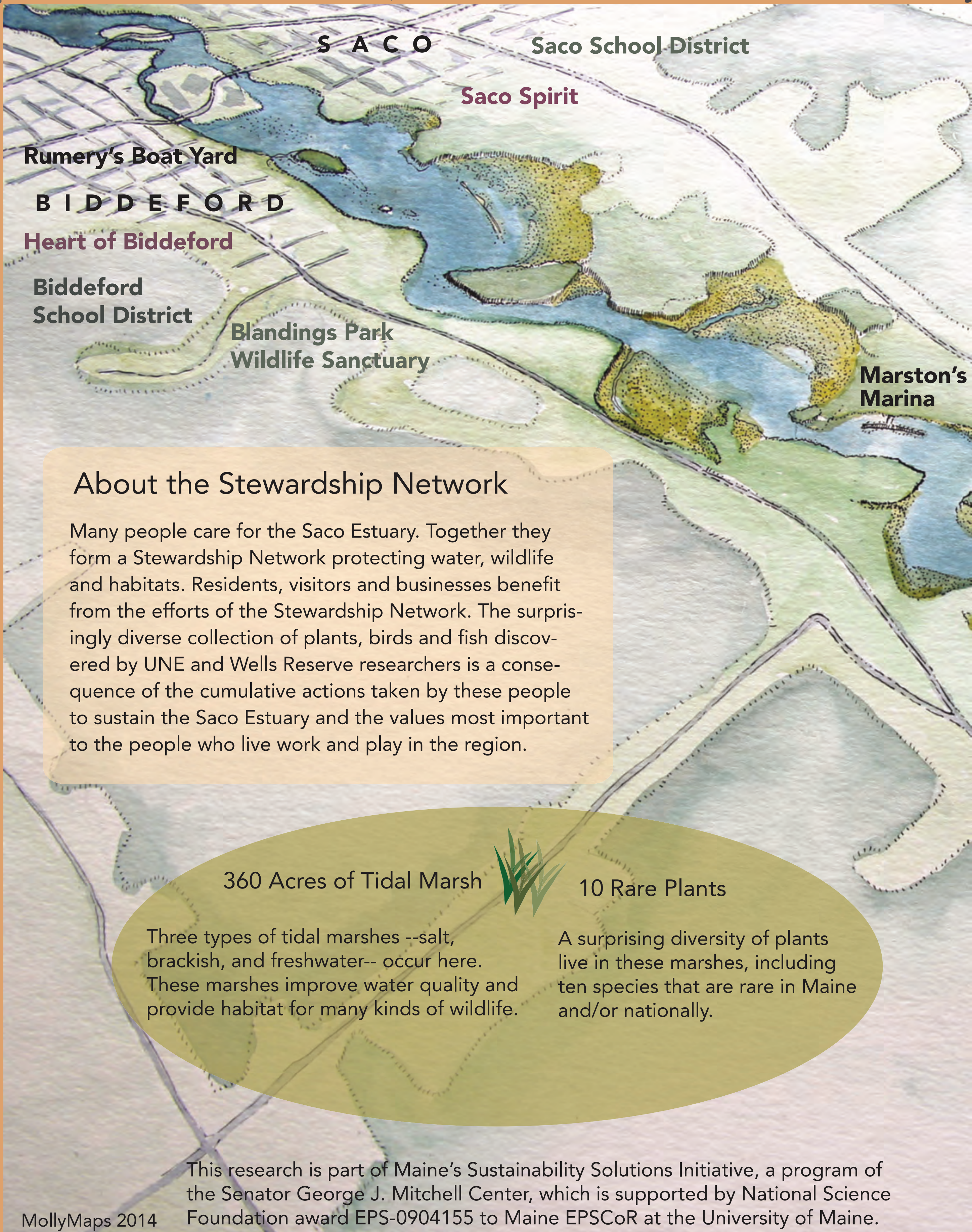
Saco River Corridor Commission · Biddeford-Saco Chamber of Commerce and Industry

Town of Biddeford: Planning Board, Open Space Committee, Conservation Commission, Shellfish Conservation Committee



About the Stewardship Network

Many people care for the Saco Estuary. Together they form a Stewardship Network protecting water, wildlife and habitats. Residents, visitors and businesses benefit from the efforts of the Stewardship Network. The surprisingly diverse collection of plants, birds and fish discovered by UNE and Wells Reserve researchers is a consequence of the cumulative actions taken by these people to sustain the Saco Estuary and the values most important to the people who live work and play in the region.

360 Acres of Tidal Marsh

Three types of tidal marshes --salt, brackish, and freshwater-- occur here. These marshes improve water quality and provide habitat for many kinds of wildlife.

10 Rare Plants

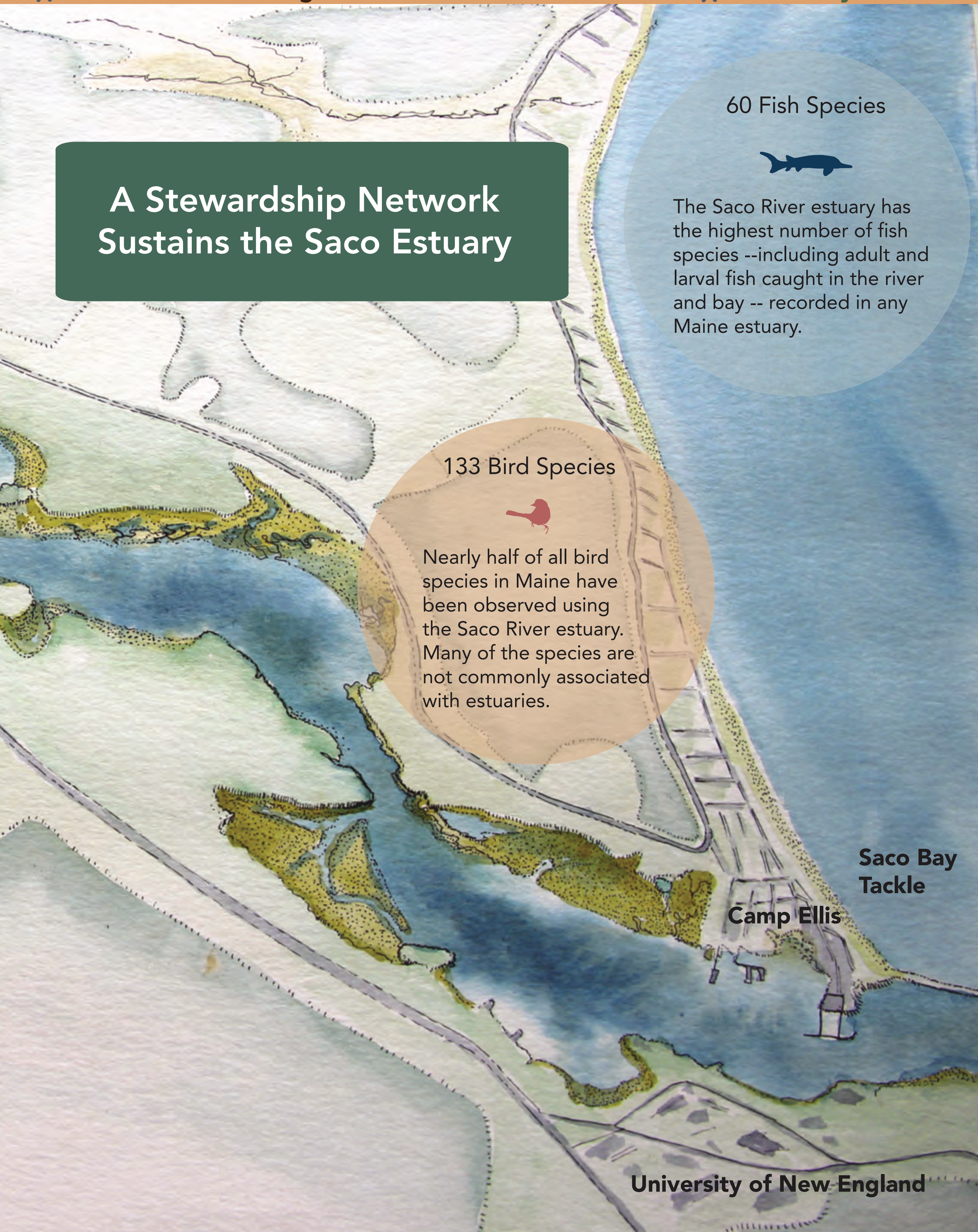
A surprising diversity of plants live in these marshes, including ten species that are rare in Maine and/or nationally.

This research is part of Maine's Sustainability Solutions Initiative, a program of the Senator George J. Mitchell Center, which is supported by National Science Foundation award EPS-0904155 to Maine EPSCoR at the University of Maine.

State of Maine: DEP, DMR, DIFW · Wells National Estuarine Research Reserve

Town of Saco: Planning Board, Conservation Commission · Saco Valley Land Trust · Saco River Salmon Club · Biddeford Saco Water · Coastal Waters Commission · Biddeford Pool Land Trust · Friends of Wood Island Lighthouse · Rachel Carson National Wildlife Refuge

A Stewardship Network Sustains the Saco Estuary



60 Fish Species

The Saco River estuary has the highest number of fish species --including adult and larval fish caught in the river and bay -- recorded in any Maine estuary.

133 Bird Species

Nearly half of all bird species in Maine have been observed using the Saco River estuary. Many of the species are not commonly associated with estuaries.

CHAPTER 1

INTRODUCTION

WHY IS THE SACO ESTUARY AN IDEAL LIVING LABORATORY FOR SUSTAINABILITY SCIENCE?

BY CHRISTINE B. FEURT and PAMELA A. MORGAN

The Saco Estuary had not been researched in a focused interdisciplinary way

The Saco River watershed is the largest watershed in southern Maine. With headwaters in the White Mountains of New Hampshire, it encompasses more than 4,400 km^2. The Saco River watershed provides clean healthy drinking water to over 100,000 people living and working in communities in southern Maine. The ten-kilometer long estuarine portion of the river lies below the first dam on the river and features a variety of coastal habitats, including tidal wetlands, rocky outcrops, sand beaches and mudflats. Salinities in the estuary range from 0 ppt near the dam to 10–32 ppt at the river's mouth (Fitzgerald et al. 1993). This stretch of the river is bordered by the cities of Saco and Biddeford (Figure 1). The University of New England (UNE) is located in the city of Biddeford, at the mouth of the Saco River. Proximity to the estuary and Gulf of Maine is a factor in many students' decisions to attend UNE.

When the Saco Estuary Project began in 2009, the ecology of the Saco River estuary was not well understood. Very few scientists had studied its fish or bird populations, and only a limited amount of information (from the Maine Natural Areas Program) existed about the estuary's plant communities. Researchers at UNE were interested in understanding how the physical attributes of the watershed such as water quality and flow of pollutants and nutrients from headwaters to the ocean interact with the land use in the region to affect the plants and animals using the estuary for habitat, breeding, migration and feeding.

Scientists were also interested in understanding the social and economic characteristics of the region surrounding the estuary and how the quality of life and sense of place that people experience can be understood as part of a linked social-ecological system. This is a new name for an old idea. Linkages between the ecological system and social system can be viewed through the lens of history and the cultural heritage of the Saco River estuary that people have called home for

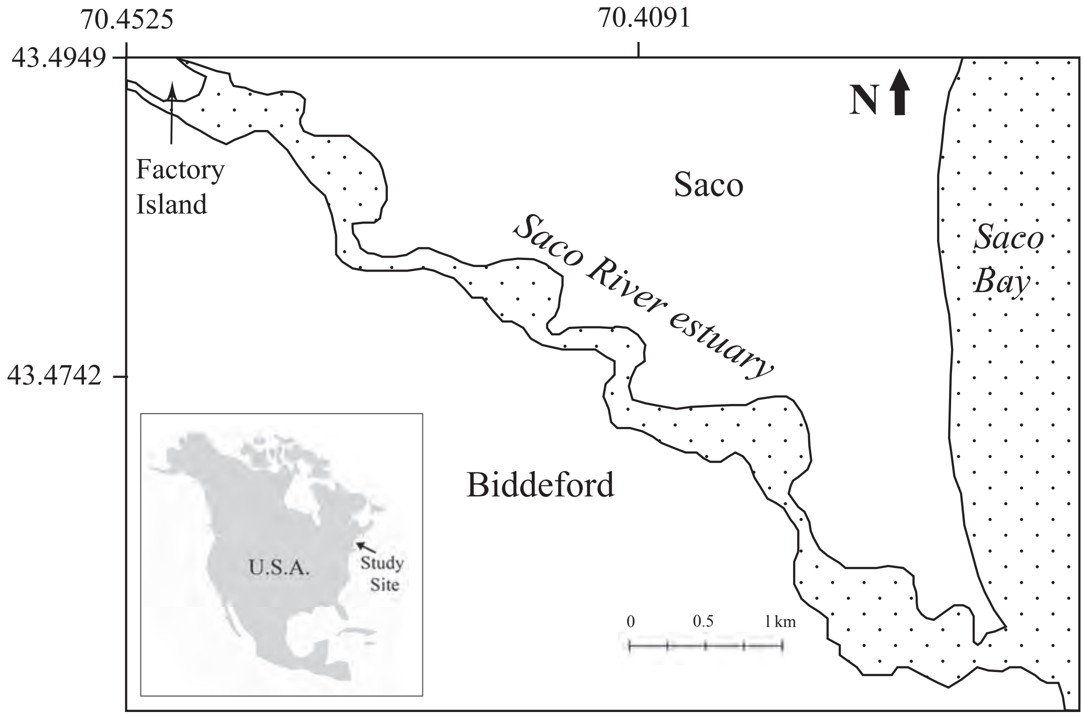


FIGURE 1 Map of the Saco Estuary, which extends from near Cataract Dam at Factory Island to the river mouth.

hundreds of years. The concept of a creating a resilient social-ecological system focuses on how the people living in a place work together to build relationships, support a robust economy, and protect the natural systems that contribute to human wellbeing. The Saco Estuary Project research revealed surprising improvements in the ecosystem health of the Saco Estuary and connected the actions of organizations, governments and local groups to the improvements.

Environmental change in the Saco Estuary is linked to social change

The Saco River has always been a focal point for life in the region. The area has a rich history, being home first to the Abenaki people, and then settled by Europeans in 1631. Samuel de Champlain visited the estuary in 1605 and described seeing Native Americans growing corn, beans and squash at the mouth of the river (Figure 2). During the 18th century the area's rich natural resources provided for an economy based on lumbering, ship building and farming. Where the Saco River ran between downtown Biddeford and Saco, it narrowed around Factory Island and flowed over two falls, which provided the energy for the growth of manufacturing in the early 19th century. Textile mills came to dominate the local economy as Biddeford and Saco grew to be booming industrial cities. The industrial boom had consequences for the ecosystem health of the estuary. Construction of dams and chemical runoff from the cities were the legacy of industrial success, but they polluted the Saco River downstream of the mills and blocked the ancestral migration routes of fish species. These changes produced enduring ecological

FIGURE 2 Samuel de Champlain mapped the Saco Estuary in 1605.

Citation: Champlain, Samuel de (1567?-1635). "Chaouacoit" [facsimile]. Paris: J. Berjon, 1613. As reproduced by, Biddeford, Me.: McArthur Public Library, mcamap.0036, circa 1950.

consequences for water quality and wildlife and represent a loss for the wellbeing of people living in the region who depended upon fish resources and clean water.

Economic conditions led to the closing of the mills in the 1960's. National water quality legislation in the 1970's contributed to improvements in water quality as the Saco Estuary began to recover from some of the ravages of economic boom of the mill era. Today, Biddeford is the sixth most populated city in the state of Maine with more than 22,000 residents, and Saco's population of more than 15,500 has been steadily growing. The cities of Biddeford and Saco are working to create a shared identity as a vibrant place for people and businesses. One of the focusing elements of their shared vision is the Saco River and its importance to the region's heritage, economy, and the wellbeing of people who live, work and play along its shores. While the impacts of the mills on the river have declined, coastal development, increasing population density, changing land use and climate change will all play a role in determining the long-term sustainability of qualities of the Saco Estuary that are important to the people in the region. Social and land use changes associated with increasing development will be exacerbated by anticipated changes in weather patterns, including increased incidents of intense rainfall, drier summers and sea level rise affecting both natural systems and built infrastructure. There is a pressing need for scientific research to help us understand the status of the estuary and to be able to monitor change over time. Information that indicates the health of the estuary can be used to inform decisions, evaluate the effects of local policies and showcase success stories where local actions have conserved and restored locally valued conditions.

The Saco Estuary Project was part of a statewide initiative funded by the National Science Foundation and coordinated by the University of Maine

In 2009 as part of a collaborative National Science Foundation (NSF) EPSCoR grant, researchers from the University of New England and the Wells National Estuarine Research Reserve began a directed program of scientific research on the Saco Estuary. The National Science Foundation awards this type of grant, the Experimental Program to Stimulate Competitive Research (EPSCoR), with a specific goal of building the capacity of a state to conduct innovative cutting-edge research through partnerships that include colleges and universities, private industry, government and others. Maine EPSCoR at the University of Maine oversees and implements the state's NSF EPSCoR programs. The five-year statewide research program that began in 2009 and ended in 2014 was called Maine's Sustainability Solutions Initiative (SSI). Maine's Sustainability Solutions Initiative was inspired by a 2006 Brookings Institution report, *Charting Maine's Future: An Action Plan for Promoting Sustainable Prosperity and Quality Places.*

The Saco Estuary Project was one of a suite of research projects across the state aimed at applying sustainability science to address complex issues important to the people of Maine.

What is sustainability science and how did it shape the Saco Estuary Project?

The Sustainability Solutions Initiative introduced the Maine research community to sustainability science. What is sustainability science, and how did it influence the design and execution of the Saco Estuary Project? Kates et al. (2001) described sustainability science as a distinct field of study that "seeks to understand the fundamental character of interactions between nature and society… and on society's capacity to guide those interactions along more sustainable trajectories." Many researchers have discussed the salient characteristics of sustainability science in the scientific literature as the field has emerged and evolved over the past two decades.

The Maine Sustainability Solutions Initiative developed criteria guiding all of the research projects in the state with the goal that the projects would advance sustainability science and education priorities while focusing on solutions to unique social-ecological problems in the state. All of the elements below were incorporated into the Saco Estuary Project. The sustainability science approach was new to researchers and students at UNE and Wells NERR and to the many stakeholder groups who worked with researchers during the five years of the project.

The Saco Estuary Project incorporated the following sustainability science criteria:

1. Develop integrated, interdisciplinary teams in which researchers and other partners are committed to working together for research and education on the estuary.
2. Create new and integrated research, education, or service learning (internship) opportunities for students in the research focus area.

3. Identify local groups (stakeholders) who care about sustaining the ecosystem health of the estuary.
4. Fully engage stakeholders whose work and interests connect to the estuary and who are concerned about ecosystem health and how it is integrated with important community values.
5. Work with stakeholders in place-based dialogues to create information collaboratively that is relevant to improving situations identified as important.
6. Support the development of student job skills and competencies in Science Technology, Engineering and Math (STEM) fields related to the research focus.

How did these criteria play out in the Saco Estuary Project? Local, state and federal government officials, conservation and watershed groups, businesses, land trusts and interested citizens partnered with UNE faculty and students and scientists from the Wells National Estuarine Research Reserve to engage in collaborative research. Together they shaped the goals of the project to understand how coastal wetlands, birds and fish populations could be indicators of the ecological health of the estuary. The wetlands, birds and fish that depend upon the estuary are affected by pollution that runs off the land, increased amounts of pavement in the areas that drain to the estuary and altered rainfall and temperature patterns affected by climate change. Groups like the Saco River Salmon Club, Saco River Corridor Commission, Biddeford Conservation Commission and Open Space Committee and the Coastal Water Commission share concern for these issues. These issues have the potential to affect local business owners, prompting business owners and the Biddeford Saco Chamber of Commerce and Industry to join other project stakeholders to contribute to and learn from the project.

Researchers and stakeholders partnering through the Saco Estuary Project were interested in understanding how the current social and economic characteristics of the region connected to the ecosystem health of the estuary. Using videos and photographs, student researchers identified and documented the ways people use the estuary for livelihoods and recreation and how businesses depend upon the health of the estuary. Student research was augmented by a Maine PBS documentary focusing on the changes in the Saco Estuary resulting from changes in policies and management. During the project, students learned from local officials and community leaders about the mechanisms used by governments, businesses and organizations to understand and protect the ecological, social and economic values of the estuary. Five years of researcher, student and stakeholder engagement activities helped to build a shared understanding about ways to manage and protect the natural assets of the estuary, build a resilient economy connected to those natural assets and conserve the rich cultural heritage linked to the estuary.

The remaining chapters in this technical report present the results of each aspect of the research, stakeholder engagement, education and outcomes of this research.

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CHAPTER 2

RECOGNIZING AND ENGAGING THE STEWARDSHIP NETWORK

ACTIVELY WORKING TO SUSTAIN THE SACO ESTUARY

BY CHRISTINE B. FEURT

What was the novel approach scientists used to learn about the ecological health of the Saco Estuary?

In 2009, scientists at the University of New England (UNE) and the Wells National Estuarine Research Reserve (Wells NERR) gathered to develop a unique research strategy for learning about the health of the Saco Estuary. The research strategy contained elements of traditional ecological research. This included studies to learn how physical attributes of the watershed such as water quality, flow of pollutants from the land, and local land use interact to affect the plants and animals using the estuary. A novel approach used for the first time at UNE made the research strategy unique. This novel approach integrated natural science research with social science approaches and deliberate engagement with the people whose actions contribute to the ecosystem health of the estuary.

Researchers were interested in understanding the *social-ecological system* associated with the Saco Estuary. The social-ecological system is more than water, tidal wetlands and fish. The social-ecological system includes all of the ways people interact with and depend upon the natural system. How do people use the estuary for livelihoods and recreation? How do businesses depend upon the health of the estuary? What are the mechanisms used by governments, businesses, and organizations to understand, protect and balance trade-offs that affect the ecological, social and economic values of the estuary that contribute to human well-being?

This new approach called *sustainability science* integrates the diverse disciplines of researchers with the work of stakeholder groups who are part of the social-ecological systems they are studying (Clark and Dickson, 2003). The initial goal of the Saco Estuary Project was to assess the ecosystem health of the Saco Estuary. The results of this research, detailed in this report, provide a baseline assessment of the condition of this previously understudied social-ecological system. This baseline assessment contributes to a longer-term goal to sustain and restore the structure and function of the estuary and support the efforts of government, businesses and local organizations that value the estuary and depend upon the natural services it provides. Scientists and resource managers call these natural services that flow from healthy ecosystems *ecosystem services.* Drinking water, flood protection, pollution control, commercially viable fisheries and recreation are all examples of the ecosystem services that flow from the Saco River.

What groups, businesses and organizations care about and contribute to the ecosystem health of the Saco Estuary?

During the first year of the Saco Estuary Project an assessment of groups working to sustain the natural benefits or ecosystem services of the Saco revealed the complex architecture of what came to be called the *Stewardship Network* for the Saco Estuary. The Stewardship Network operating in the region includes municipal, state and federal governments, volunteer municipal boards making land use decisions, water supply organizations, land trusts, businesses, property owners and organizations that are uniquely focused on the region, such as the Saco River Salmon Club and the Saco River Corridor Commission. Each member of the Stewardship Network focuses on a unique suite of interests, approaches and responsibilities that contribute to sustaining valued qualities of the estuary. Together this network accomplishes some of the most important objectives of community-based ecosystem management to sustain ecosystem services (Meffe et al, 2002; Feurt, 2008).

The work of the Stewardship Network is accomplished in many ways. Examples of this work include the development of the Biddeford Open Space Plan by the Biddeford Conservation Commission and Open Space Committee. Using information about natural habitats and current land cover, and knowledge about the locations of special places valued by local community members, this group identified mapped and prioritized areas to be conserved and protected in Biddeford. The work of local planning boards, zoning boards and code enforcement officers contributes to the protection of shoreline buffers important for flood protection, water quality and critical habitat. The work of the Saco River Corridor Commission is unique in the State of Maine — providing increased protection for the shorelines of the main stem of the Saco River. The work of this group helps to ensure that drinking water quality, flood protection and habitat ecosystem services from the river are safeguarded.

People understand and value the lands and water that contribute to community wellbeing. Undergraduate researchers at UNE conducted an assessment of the work of the Stewardship Network and asked participants in a community workshop to identify valued qualities of the Saco Estuary and its watershed.

The members of the Stewardship Network participating in the Saco Estuary Project are listed below in alphabetical order. Representatives from these groups attended workshops, interacted with student researchers, advised scientists on the project and remained enthusiastically committed to the goals of the project—to sustain the structure and function of the ecological systems of the Saco Estuary. The ecological condition of the estuary is a reflection in part of the collective work of these groups.

The Saco Estuary Stewardship Network (2009–2014)

Biddeford Pool Land Trust
Biddeford-Saco Chamber of Commerce and Industry
Biddeford Saco Water (Maine Water)
Blanding's Park Wildlife Sanctuary
City Of Biddeford
- Biddeford Code Enforcement
- Biddeford Conservation Commission
- Biddeford Engineering, Stormwater Management and Public Works
- Biddeford Open Space Committee
- Biddeford Planning Department and Planning Board
- Biddeford Shellfish Commission
- Biddeford Wastewater Treatment Facility

City of Saco
- Saco Code Enforcement
- Saco Conservation Commission
- Saco Engineering and Public Works
- Saco Planning Department and Planning Board
- Saco Wastewater Treatment Facility

Coastal Waters Commission
Cumberland County Soil and Water Conservation District
Friends of Wood Island Lighthouse
Heart of Biddeford
Maine Coastal Program
Maine Department of Environmental Protection
Maine Department of Inland Fisheries and Wildlife
Maine Department of Marine Resources
Maine Department of Transportation
Maine Drinking Water Program
Maine Geological Survey
Maine Natural Areas Program
Marston's Marina
Rumery's Boat Yard
Saco Bay Trails
Saco Farmer's Market
Saco Valley Land Trust
Saco Bay Tackle Company
Saco River Corridor Commission
Saco River Salmon Club
Southern Maine Planning and Development Commission
The Nature Conservancy of Maine
Thornton Academy
University of New England
USDA Natural Resource Conservation Service
US Fish and Wildlife Service, Gulf of Maine Office
US Fish and Wildlife Service, Rachel Carson National Wildlife Refuge
US Environmental Protection Agency Boston Office
Wells National Estuarine Research Reserve

Members of the Stewardship Network bring diverse expertise, knowledge and skills to the work they do that contributes to sustaining the ecosystem services of the Saco Estuary. Knowledge in the network includes engineering practices, stormwater management, sustainable business practices, pollution prevention, land conservation and land use planning. This work is motivated and inspired by a sense of place, awareness of local culture and a commitment to maintaining local heritage for future generations (Feurt, 2012). Each member of the Stewardship Network contributes to sustaining the ecosystem services of the Saco in different ways. This includes development of ordinances and regulations and their enforcement, land use planning and management, environmental monitoring and research, habitat conservation and restoration, education and community outreach, engineering, wastewater and public works, and drinking water provision. All elements of this *Kaleidoscope of Expertise* contribute to sustaining and restoring the qualities of the estuary that are important to the wellbeing of local residents (Feurt 2007; 2008; 2012). Figure 1 illustrates the *Kaleidoscope of Expertise* of the Stewardship Network for the Saco Estuary. Table 1 shows examples of each type of group represented by the *Kaleidoscope of Expertise*.

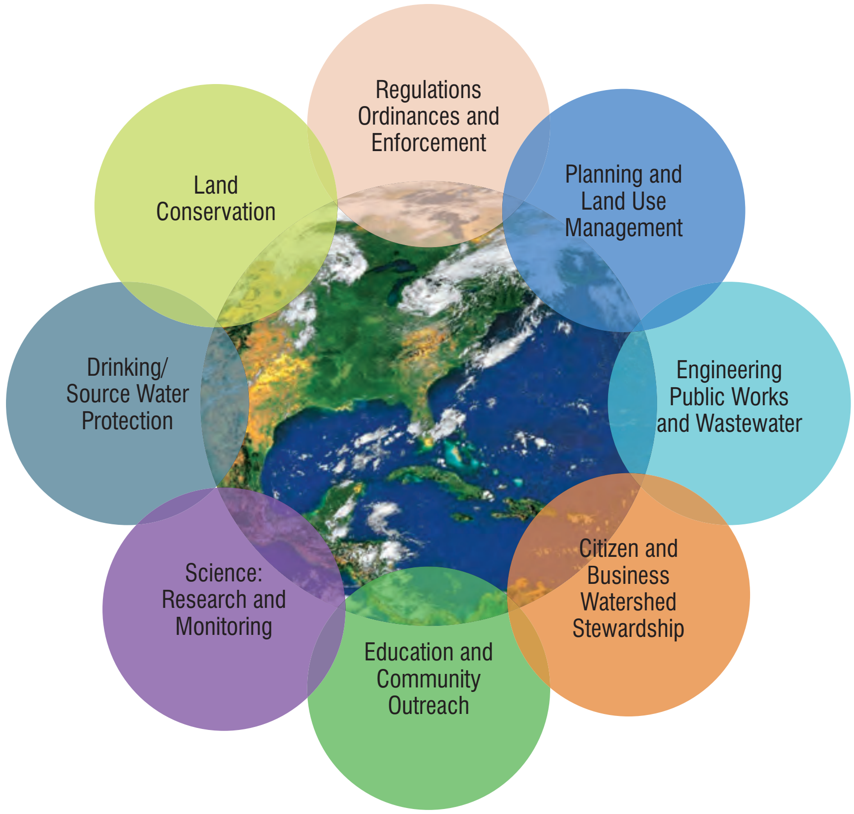

FIGURE 1 The Kaleidoscope of Expertise. Collaborative learning engages the stewardship network to sustain ecosystem services of the Saco Estuary.
Photo credit: Blue Marble by NASA, public domain.

How was Collaborative Learning used to build a bridge connecting knowledge to action?

One challenge that emerged early in the Saco Estuary Project was finding a way to link the scientific discoveries of the researchers with the work of the Stewardship Network. Sustainability science has adopted the term *knowledge to action* to capture the concept of bridging knowledge to decision-making across boundaries separating science and policy, between disciplines, across geographic scales and levels of management (Cash et al. 2003). Linking knowledge to action in sustainability science requires effective interactions among stakeholders and scientists. The research team used an approach called Collaborative Learning.

The Collaborative Learning approach facilitates the movement of knowledge to action in social-ecological systems like the Saco Estuary. As a robust approach with theoretical roots in alternative dispute resolution, soft systems methodologies and adult learning, Collaborative Learning is especially suited to meet the challenges of boundary work that links knowledge to action. Collaborative Learning includes principles and adaptable practices to enable diverse groups of stakeholders to

TABLE 1 Saco Estuary Stakeholder Assessment: Categories of Expertise

Planning and Land Use	Regulations and Enforcement	Engineering Stormwater and Public Works	Citizen and Business Stewardship	Education and Outreach	Scientific Research and Monitoring	Drinking/Source Water Protection	Land Conservation
Saco Planning Board	Saco River Corridor Commission	UNE Waste Water Treatment	Heart of Biddeford	UNE	Wells National Estuarine Research Reserve	Biddeford-Saco Water/ Maine Water	Saco Valley Land Trust
Biddeford Planning Board	Maine Department of Environmental Protection	Biddeford Waste Water Treatment	Saco Bay Trails	Wells NERR	UNE	Maine Drinking Water Program	Biddeford Pool Land Trust
Saco Conservation Commission	Saco and Biddeford Code Enforcement	Saco Wastewater Treatment	Saco River Salmon Club	Biddeford and Saco Public and Private Schools	Biddeford Shellfish Conservation Committee		Friends of Wood Island Lighthouse
Biddeford Conservation Commission		Engineering and Public Works Biddeford and Saco	Marston's Marina				Blanding's Park Wildlife Sanctuary
Biddeford Open Space Committee			Rumery's Boat Yard				Rachel Carson National Wildlife Refuge
Coastal Waters Commission			Biddeford and Saco Chamber of Commerce and Industry				

Credit: Table developed by Samantha Mills, UNE Sustainability Intern 2013.

share knowledge of a natural resource-based system and work together to improve and sustain that system despite differing perspectives (Daniels and Walker 2001; 2012).

A local adaptation of the Collaborative Learning methodology developed through the Coastal Training Program of the Wells NERR provided the framework for work with stakeholders in the Saco Estuary region (Feurt 2007; 2008; 2012). Nationally, the Coastal Training Program develops and implements trainings, skill building and stakeholder engagement activities to improve the application of science to decisions affecting the ecosystem health of estuaries of the National Estuarine Research Reserve System (NOAA 2010). Locally, the Collaborative Learning approach developed in southern Maine integrated community-based ecosystem management (Meffe et al., 2002) and Collaborative Learning as a strategy to build ongoing partnerships among stakeholders and scientists to accomplish environmental objectives for sustaining ecosystem services. Ten years of collaboration with municipalities, watershed groups, land trusts and state and federal government resulted in ongoing partnerships that developed and implemented watershed plans and conservation plans (Feurt 2008; Feurt et al. 2010; and Salmon Falls Watershed Collaborative 2011). In the Saco Estuary Project, we adapted the Collaborative Learning methodology to bridge the interdisciplinary research of UNE and Wells NERR scientists with the on-the-ground management and policy work of the Stewardship Network.

The effectiveness of Collaborative Learning depends upon the resources and organizational capacity of the groups implementing the process. In practice, the method is resource intensive during the assessment phase and requires expert facilitation as well as buy-in from participants who must be committed to the learning and relationship building aspects that contribute to success. All of these elements came together during the five years of the Saco Estuary Project. A major contribution came from undergraduate researchers working in courses and internships sponsored by the UNE's Department of Environmental Studies - Center for Sustainable Communities under the guidance of Dr. Christine Feurt.

What do stakeholders in the social-ecological system of the Saco Estuary care about?

As part of the stakeholder assessment for the Saco Estuary Project, undergraduate researchers identified and characterized stakeholders interested in collaborating to develop indicators of ecosystem health for the Saco Estuary. Using the Collaborative Learning Guide for Ecosystem Management (Feurt 2008), a practitioner's guide to developing Collaborative Learning events, students in two Environmental Studies courses (*Ecosystem Management*, Fall 2009 and *Environmental Communication*, Spring 2010) conducted literature and internet reviews, attended stakeholder meetings and held informal meetings with diverse stakeholders to identify groups with interests and responsibilities for sustaining the ecosystem services of the Saco Estuary. Initially, twenty groups were identified including municipal staff of Biddeford and Saco, volunteer boards from the towns, land trusts, habitat and land conservation groups, and two groups with unique and strong ties to the Saco – the Saco River Salmon Club and the Saco River Corridor Commission.

Students in the Environmental Communication course created profiles of the stakeholder groups and developed a Collaborative Learning workshop, *Sustaining the Saco*, held in 2010 to bring stakeholders together to meet with scientists on the project and to share their interests and concerns about the estuary. During class time students learned how to design a Collaborative Learning event and practiced skills of small group facilitation, active listening and note taking, all required for implementing a Collaborative Learning event.

Stakeholders from the groups identified by students were invited to a three-hour Collaborative Learning workshop on the UNE campus. Food was provided to create conditions supportive for busy people coming straight from work to attend the workshop. Dr. Feurt welcomed stakeholders and scientists. Student presentations introduced each aspect of the project and defined the meaning of the term *ecosystem services*. Stakeholders were then asked to engage with a team of students assigned to each of six breakout groups to discuss four questions designed to provide input to the project. Individual students facilitated the discussions, took notes on flip charts and typed notes into laptops as well as engaged in dialogue with stakeholders. Stakeholders provided input for the following questions:

- What do you value about the Saco Estuary and region?
- What are your concerns about sustaining ecosystem services of the Saco Estuary?
- How can UNE support community and regional efforts to sustain the Saco?
- Do you have anything else you would like to share with us this evening?

Students generated a stakeholder assessment using notes from their internet research and stakeholder meetings and the Collaborative Learning workshop. They used Grounded Theory Analysis to identify the diversity of stakeholder values linked to ecosystem services of the Saco Estuary. Grounded Theory Analysis (Corbin and Strauss 1990) is a qualitative method used to systematically analyze text such as meeting notes, policy and planning documents. Specific questions are used to query the text line by line and to develop coding themes consisting of key words and concepts. As patterns in the data emerge, quotes can be sorted according to themes to build theories to explain the data. Undergraduate researchers coded the initial data to build stakeholder profiles and to answer the four questions above. Subsequent coding of that data by Feurt for ecosystem services themes appears in Table 2.

This stakeholder assessment during the first year of the project contributed to development of the Stakeholder Network concept, built an understanding of stakeholder concerns and fostered the recognition that the stakeholders in the Stewardship Network were already actively engaged in sustaining ecosystem services. However, this Stewardship Network was not integrated internally, nor was it linked to the interdisciplinary research team as they began work on the Saco Estuary Project in 2009. The first *Sustaining the Saco* Workshop in 2010 helped UNE and Wells NERR researchers understand the work of the Stewardship Network and how to engage members of the Network for the duration of the project.

TABLE 2 Qualities of the Saco Estuary valued by stakeholders value according to type of ecosystem service

ECOSYSTEM SERVICES Benefits that people obtain from ecosystems as categorized by the Millennium Ecosystem Assessment (2005)	Saco Estuary Stakeholder Values Identified from Collaborative Learning Workshop and Assessment conducted by UNE *Environmental Communication* Class Spring 2010
PROVISIONING SERVICES The products obtained from ecosystems, including, genetic resources, food and fiber, and fresh water.	• People value the Saco River watershed as the water supply and source of safe drinking water for most of southern Maine • People value the role of regulations and laws to protect provisioning services (water quality) of the Saco Estuary • People value the commercial and recreational fishing that the Saco Estuary provides
REGULATING SERVICES The benefits obtained from the regulation of ecosystem processes, including the regulation of climate, water, and some human diseases.	• People value the role of natural areas like riparian buffers and wetlands to filter water as part of the water cycle • People value the role that natural areas play absorbing flood waters
CULTURAL SERVICES The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, knowledge systems, social relations, and aesthetic values.	• People value the opportunities for recreation that the Saco Estuary provides • People value the undeveloped natural areas • People value access to the Saco Estuary • People value the aesthetics of the Saco Estuary • People value the potential of the Saco Estuary as a place for environmental education • People value the potential for research in the Saco Estuary to determine the location and condition of wildlife habitat • People value the quality of life the Saco Estuary provides to the community • People value the history of the Saco Estuary region to help identify their sense of place
SUPPORTING SERVICES those services that are necessary for the production of all other ecosystem services. Some examples include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.	• People value the potential that the resources of a healthy Saco Estuary have to support businesses/jobs for a stronger economy including a clean river and tidal wetlands supporting estuarine fish food webs. • People value conservation of natural areas and natural resources of the Saco Estuary to protect its biodiversity

ACKNOWLEDGEMENTS

The Stewardship Network whose collective actions sustain the Saco Estuary: Saco River Corridor Commission; Saco River Salmon Club; citizens of Biddeford and Saco; Biddeford-Saco Chamber of Commerce and Industry; Saco municipal government and volunteer boards; Biddeford municipal government and volunteer boards; Heart of Biddeford; Saco Valley Land Trust; Biddeford Pool Land Trust; Biddeford Pool Improvement Association; Blanding's Park Wildlife Sanctuary; Saco Coastal Waters Commission; Biddeford, Saco and University of New England (UNE) wastewater treatment facilities; Biddeford Saco Water/Maine Water; Rachel Carson National Wildlife Refuge; business owners located near and dependent on a healthy Saco Estuary; recreational users of the Saco Estuary; UNE students participating in the Environmental Studies courses "Sustaining Water" and "Environmental Communication" from 2009 to 2014 whose work engaged stakeholders in the Saco Estuary project; UNE undergraduate researchers working with the UNE Department of Environmental Studies Center for Sustainable Communities to identify, describe and engage the Stewardship Network and learn from them about actions that "Sustain the Saco"; The Wells National Estuarine Research Reserve.

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CHAPTER 3

PLANTS OF THE SACO ESTUARY

TIDAL MARSHES

BY PAM MORGAN

INTRODUCTION

Tidal marshes are wetlands composed primarily of grasses, sedges and rushes that occupy the intertidal zone—the area between low and high tide. The Saco Estuary contains more than 350 acres of tidal marshes that vary from salt marshes near the mouth of the river, to brackish marshes, to tidal freshwater marshes in the estuary's upper reaches near Cataract Dam.

Why should we care about tidal marshes?

Tidal marshes, some of the most productive habitats in the world, provide a home for a wide variety of plants and animals, including fish and birds. These habitats provide a diverse range of benefits—from aesthetics to fish habitat to water filtration. Many fish species use the surface of the marsh as a place to forage and escape from predators. In fact, tidal marshes are widely known as nursery grounds for important fish species. The fish and invertebrates of the marshes also provide an important source of food for resident and migratory birds, such as great blue herons and snowy egrets. People also value tidal marshes because they help clean coastal waters by extracting pollutants from water entering the estuary. Tidal marshes also serve as important buffer areas between developed coastal areas and the sea, absorbing the energy of incoming waves. In addition, marshes are valued highly for their beauty, which residents and visitors alike appreciate from the shore and from the water, making them an important recreational resource. One of the main reasons that scientists from the University of New England (UNE) and the Wells National Estuarine Research Reserve (NERR) have studied the Saco River tidal marshes is that very little was known about them. With this study, we now have a better understanding of the values these marshes provide and can monitor their health into the future.

What issues should we be concerned about?

In many estuaries, tidal marshes are degrading and even disappearing due to a number of human-caused threats (Gedan et al. 2011). These threats include increased coastal development and associated pollutants (especially nitrogen), climate change and associated sea level rise, increased flooding events and invasive species. *Phragmites australis*, also known as the common reed, is one invasive species of particular concern in the Saco Estuary's tidal marshes (Figure 1). This plant can quickly take over a marsh, choking out native plant species and decreasing its value as fish and bird habitat. Its dead stems have been known to catch fire, threatening nearby homes and businesses (Saltonstall 2005). Although the common reed provides some benefits to an estuary, its negative impacts have led scientists and land managers to develop a variety of methods to prevent its further spread (Saltonstall 2005).

FIGURE 1 The invasive common reed, *Phragmites australis*.

STUDY OBJECTIVES—PLANTS

Our objectives for the plant study were to answer these questions related to the tidal marshes:

1. What plants grow in the tidal marshes, and how do the plants change as one moves down the river?
2. How diverse are the plant communities in the marshes?
3. What rare and threatened plant species grow in the tidal marshes?
4. How extensive is the invasive common reed, *Phragmites australis*, in the estuary's marshes, and what should we do about it?
5. Does the extent of shoreline development affect the diversity of plants in the marshes?

RESEARCH DESIGN AND METHODS

We chose 16 marsh sites to study, located from the mouth of the river up to Cataract Dam (Figure 2). We chose these sites to capture the range of salinity in the estuary. Marshes were also selected based on the extent of shoreline development behind each site in order to study the possible impacts of shoreline development on marsh plant diversity. Using a geographic information system (GIS), we mapped the land cover/land use in a 100-meter area around each marsh site, so that we could quantify the amount of development adjacent to each marsh study site (see Chapter 7, Land Use and Land Cover Along the Saco River Estuary's Shoreline).

FIGURE 2 Tidal marsh study sites along the Saco Estuary.

FIGURE 3 UNE students sampling tidal marsh plants.

At each site we sampled plants using established methods for tidal marshes (Neckles and Dionne 2000) and determined percent cover of each plant species in one-square-meter quadrats along transects (Roman et al. 2001) (Figure 3). We also measured the salinity of the soil porewater at 15 to 20 centimeters deep in each quadrat using soil sippers and a handheld refractometer. This instrument measures how salty the water is where the plant roots are growing. Ten marshes were sampled in 2010, five more in 2012, and one more in 2013. In addition in 2010, 2011, and 2013, we sampled porewater salinity once each month (June, July, and August) at five sampling points in each marsh, again according to established methods (Neckles and Dionne 2000).

Mapping of *Phragmites australis* patches was done primarily by kayak. We used a handheld GPS with sub-meter accuracy (Trimble GEOXT-6000) while walking the perimeter of each patch we found. The density and height of stems was determined in the field, and plants in each patch were identified to determine whether they were the invasive form of *Phragmites* (there is a less common, native form of *Phragmites australis* as well) (Swearingen and Saltonstall 2010).

RESULTS AND DISCUSSION

What plants grow in the marshes?

We discovered that these marshes contain a diversity of plant species, changing as one moves from the river mouth up to the dam. The species of plants growing in the marshes depends to a large degree on marsh soil salinity, which is influenced by the incoming tides, freshwater inputs to the marshes from upstream, and local surface and groundwater inputs. Figure 4 shows the most common plants at each site and the soil porewater salinity when sampled in July. Figure 5 shows soil porewater salinities recorded in summer sampling from 2010 to 2013.

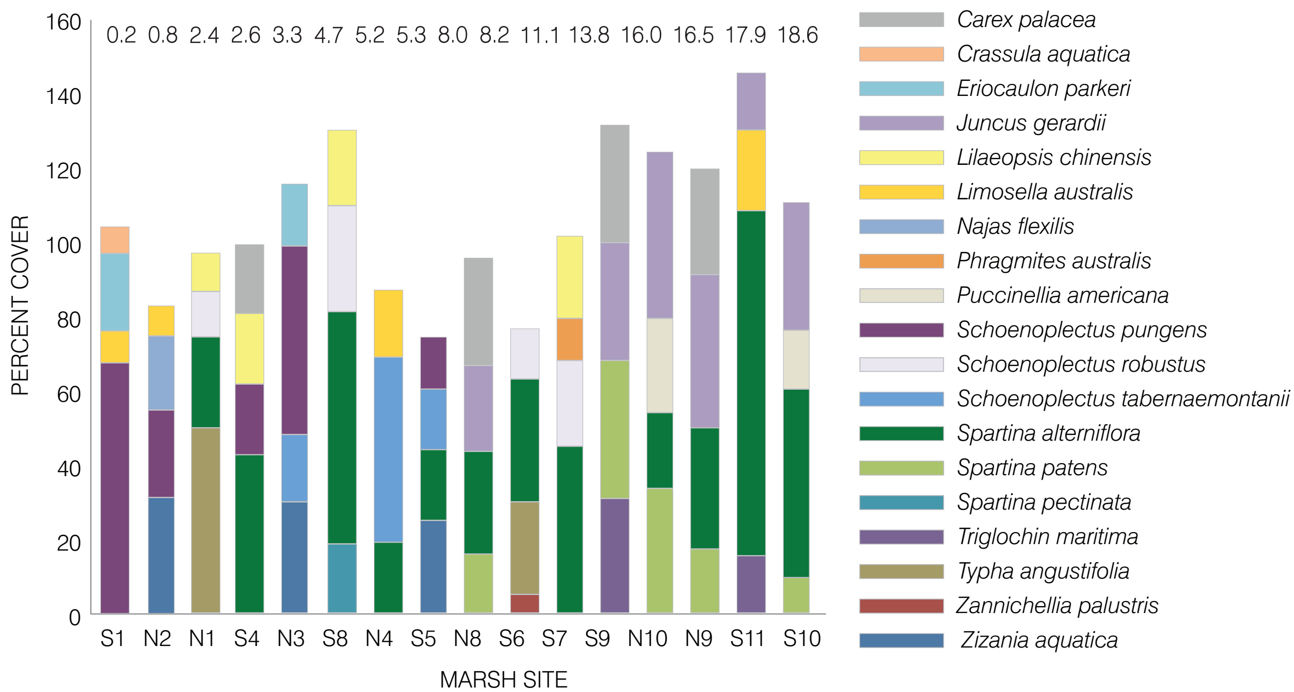

FIGURE 4 The most common plants found at each tidal marsh study site. Colored bars show the mean percent cover of each common species at a site. Numbers across the top of each bar are the soil porewater salinities (ppt) at sites in July, when plant sampling was conducted.

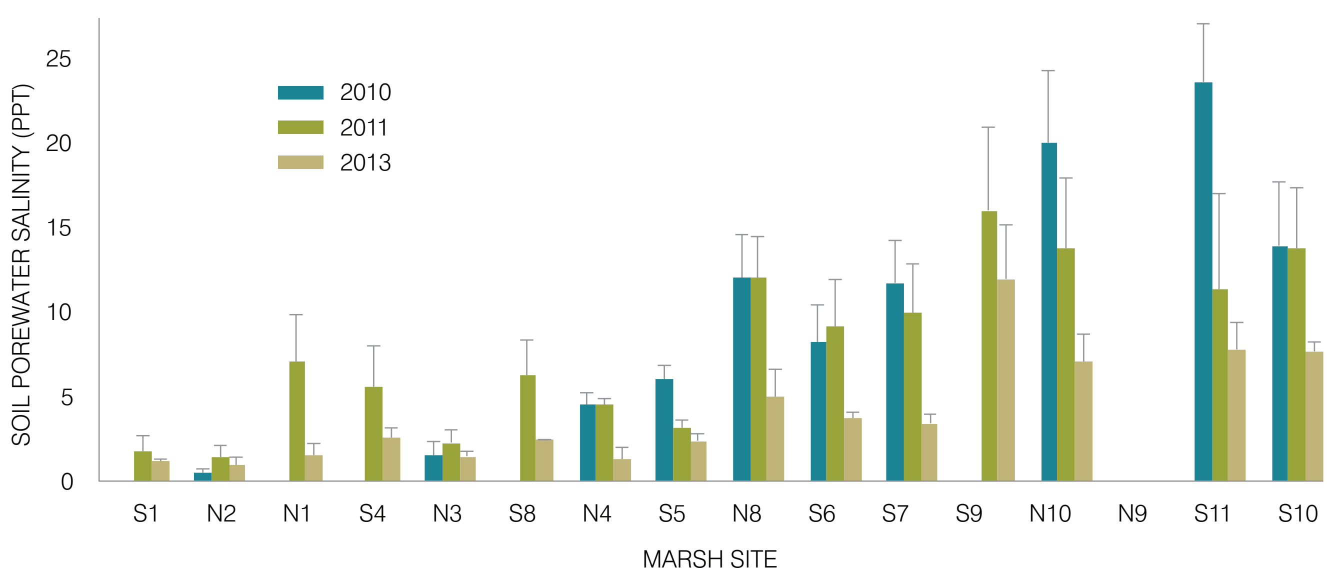

FIGURE 5 Soil porewater salinities at marsh sampling sites. Bars show means (± 1 standard error) of monthly averages for June, July, and August.

How diverse are the plant communities in the tidal marshes?

One way we can measure biodiversity is by counting the number of different species in a habitat. This is called species richness, denoted by the letter “S.” Another way to quantify species diversity is by calculating a diversity index, such as the Shannon-Wiener Index (H).

We estimated plant species diversity at each tidal marsh study site (Table 1) and found that, for the most part, the farther upstream a site was located, the greater the number of plant species it had (Pearson correlation coefficient $r=0.57$). However, plant diversity as estimated by the Shannon-Wiener index did not show this correlation as strongly ($r=0.33$). The number of species at a site is usually related to the size of the area sampled, so we would expect larger marshes to have

TABLE 1 Plant diversity at tidal marsh sites as measured by the number of species (S) and the Shannon-Wiener Index (H). Salinities are means (±1 standard error) of July porewater measurements taken from plant sampling quadrats at each site.

Site	S	H	Salinity (ppt)	Marsh area (m^2)	Distance from site to river mouth (m)
S1	15	1.683	0.2±0.1	34,646	7,000
N2	20	2.144	0.8±0.2	7,536	6,904
N3	30	2.574	3.3±0.3	77,331	6,309
S5	22	2.512	5.3±0.4	34,812	4,799
N4	35	2.582	5.2±0.3	31,447	4,644
S4	24	2.552	2.6±0.3	7,781	4,490
N1	23	1.879	2.4±0.5	6,851	3,865
S8	20	2.336	4.7±0.7	2,045	3,621
S6	13	1.812	8.2±0.9	12,423	3,192
N8	17	2.218	8.0±0.6	50,718	2,572
S7	16	2.135	11.1±0.8	2,819	2,343
S9	15	2.375	13.8±1.0	27,727	1,579
N10	18	2.149	15.9±0.9	29,513	1,202
S10	14	1.833	18.6±2.9	5,840	1,015
S11	10	1.543	17.9±1.2	1,829	562
N9	13	1.952	16.5±1.1	14,859	478

more species. We observed this trend at our study sites, but it was not a particularly strong relationship (r=0.4 for both S and H).

It is noteworthy that the Saco River's tidal marshes display the classic gradient from salt marshes to brackish marshes to tidal freshwater marshes over a relatively short distance. The distance from the mouth of the river to the Cataract Dam at the head of tide is less than 5 miles (8 kilometers).

Are there rare and threatened plant species in the marshes?

We knew from the Maine Natural Areas Program that rare plants had been observed in the Saco Estuary, and so we looked for those plants at our study sites. Rare plants are defined by the State of Maine as species that are found in few places or species that may require unique or rare habitats to survive. We found 10 rare plant species, and many of these plants appeared to be thriving in the tidal marshes (Table 2).

How extensive is the invasive common reed, *Phragmites australis*?

In summer 2013, we located 33 patches of the invasive *Phragmites australis* in the estuary's marshes (Figure 6). The majority of these patches were small in area, less than 100 square meters, and some included very few stems (Figure 7). There was

TABLE 2 Rare plants found in Saco Estuary tidal marshes.

Species name	Common name	State rank	State status
Agalinis maritime	Saltmarsh false-foxglove	Uncommon S3	Special concern
Bidens hyperborean	Northern beggar-ticks	Uncommon S3	Special concern
Crassula aquatic	Pygmy-weed	Rare to uncommon S2S3	Special concern
Eriocaulon parkeri	Parker's pipewort	Uncommon S3	Special concern
Lilaeopsis chinensis	Eastern grasswort	Rare S2	Threatened
Limosella australis	Atlantic mudwort	Uncommon S3	Special concern
Sagittaria calycina (now known as *S. montevidensis*)	Spongy-leaved arrowhead	Uncommon S3	Special concern
Sagittaria rigida	Sessile-fruited arrowhead	Rare S2	Threatened
Samolus valerandi	Seaside brookweed	Uncommon S3	Special concern
Zannichellia palustris	Horned-pondweed	Rare S2	Special concern

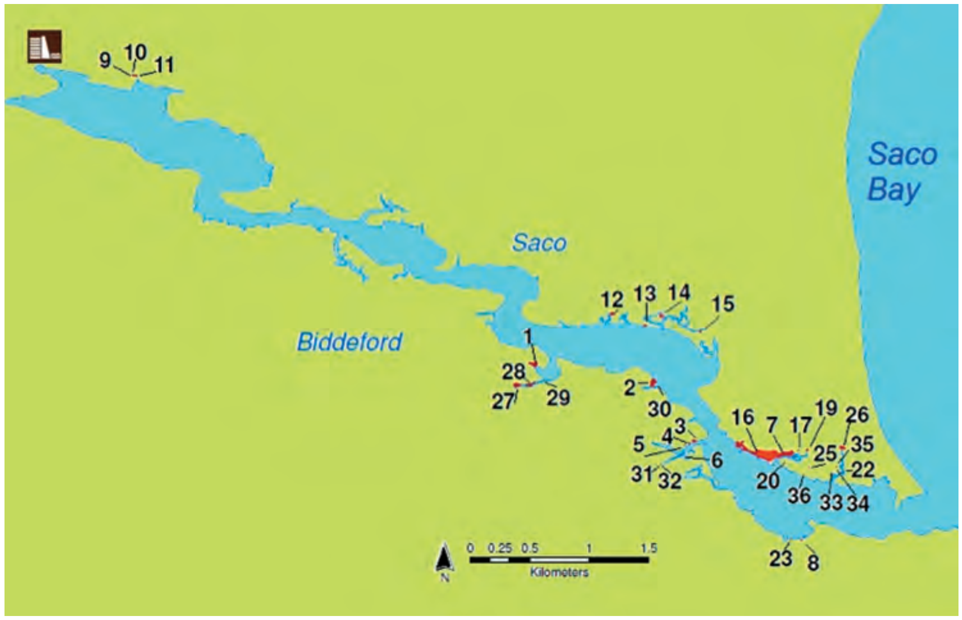

FIGURE 6 *Phragmites australis* patches in the Saco Estuary, mapped in 2013.

one very large patch near the mouth of the river that local residents have tried to keep in check by mowing and weed-whacking part of it each year. There were also several mid-sized patches that appeared to be spreading quickly, growing into the marshes and choking out native plants.

We tested the seed viability of 13 of the patches and found that plants in five of these patches produced seeds that would sprout and grow, although germination rates were low (0.4–1.3%). This means that *Phragmites* in the Saco Estuary can spread either by seed or by the fragmentation of underground stems, called rhizomes. The results of our drifter study to discover where most of these seeds or rhizome fragments might travel suggest that they primarily move downstream, and often travel up tidal creeks, where they could get caught and germinate.

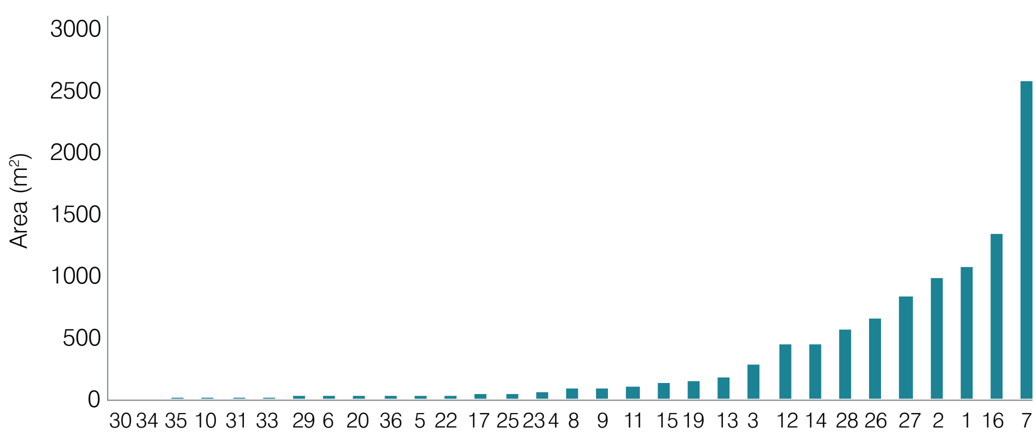

FIGURE 7 Size of *Phragmites australis* patches in the Saco Estuary. Note that patch 16 has been mowed, so its actual size is much larger.

What does this mean for the future of the Saco Estuary?

The good news is that the amount of *Phragmites australis* in the estuary is currently relatively small, but the concern is that this invasive plant is spreading. Existing patches appear to be increasing in area, small patches are appearing, and viable seeds are being produced. If we want the marshes to continue to support a diversity of native plants and healthy populations of invertebrates and fish, and to maintain the current views of the river from the shoreline, a management plan is needed.

Is development along the river's shoreline affecting the tidal marshes?

The State of Maine's Shoreland Zoning Act (Title 38 MRSA Sections 435-449) requires that Maine's municipalities adopt ordinances to regulate land use activities within 250 feet of the shoreline. Research in other estuaries has documented that shoreline development can affect tidal marshes in adverse ways, resulting in loss of marsh plant species biodiversity and an increase in invasive *Phragmites australis* (Gedan et al. 2011). Increased development can also lead to greater inputs of nitrogen pollutants to tidal marshes, which can cause changes in marsh plant communities and even the degradation of the marsh itself, as marsh soils decompose and erode away (Deegan et al. 2012). Of course, compared to areas farther south, Maine's coast is still relatively undeveloped. However, development pressure is a fact of life along the shorelines of southern Maine, so understanding the impacts of this development on our coastal habitats is important.

Understanding whether shoreline development affects marsh plant diversity is challenging because there other factors that affect diversity, such as soil porewater salinity and the size of the marsh, as discussed previously. However, when we look at the relationship between the extent of development adjacent to our marsh study sites and plant diversity, we do see a relationship. In Figure 8, the marsh sites (represented by triangles) are separated from each other on the graph according to the degree of similarity of their plant communities. Added to this are other factors that help explain the variation in plant communities at the sites. The extent of development adjacent to each marsh is an important factor. At this point, we cannot say that the extent of development is *causing* these differences in the plant communities, but we did find a relationship between the percent of highly developed land in the buffer areas around the marsh sites (i.e., 80% or more of the surface area is impervious) and marsh plant diversity as measured by the Shannon-Wiener Index (Pearson correlation coefficient $r=0.56$) and also the number of species per site (S) ($r=0.51$) (Figure 9). (See Chapter 7 for more information on land cover categories). Note that in this analysis, we looked at the land cover within 100 meters around each marsh study site, excluding marsh and mudflat habitat.

We also found a weak correlation between the amount of the buffer that was highly developed and the amount of available nitrate in the soil (measured at 10 study sites in June through August 2011, $r=0.37$). Researchers studying other tidal marshes in New England have found that coastal development contributes excess nitrogen to tidal marshes, leading to changes in the ecology of those marshes

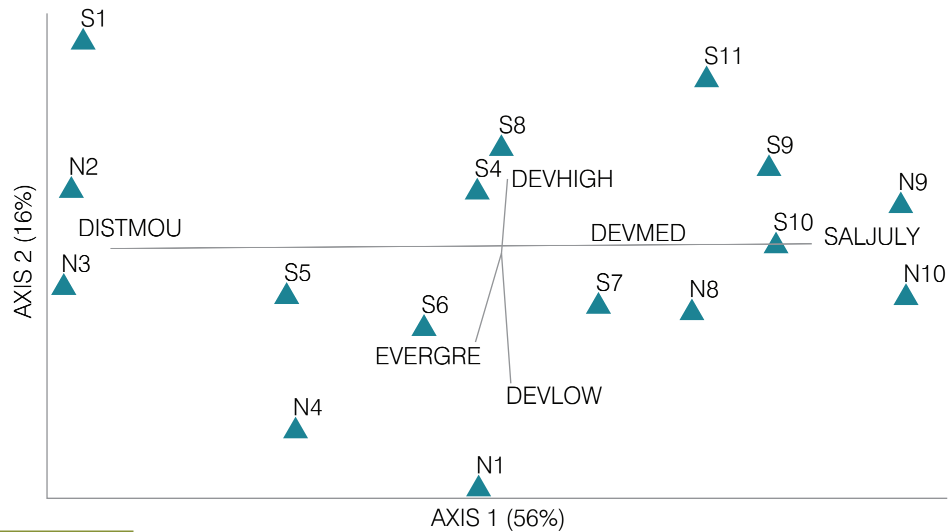

FIGURE 8 NMS ordination diagram showing the separation of the 16 marsh study sites (triangles) according to their plant communities. Also shown are the six most influential abiotic variables (intensity of development along the adjacent shoreline (DEV_HIGH, DEV_MED and DEV_LOW), proportion of evergreen cover, distance of sites to the mouth of the river, and soil porewater salinity in July).

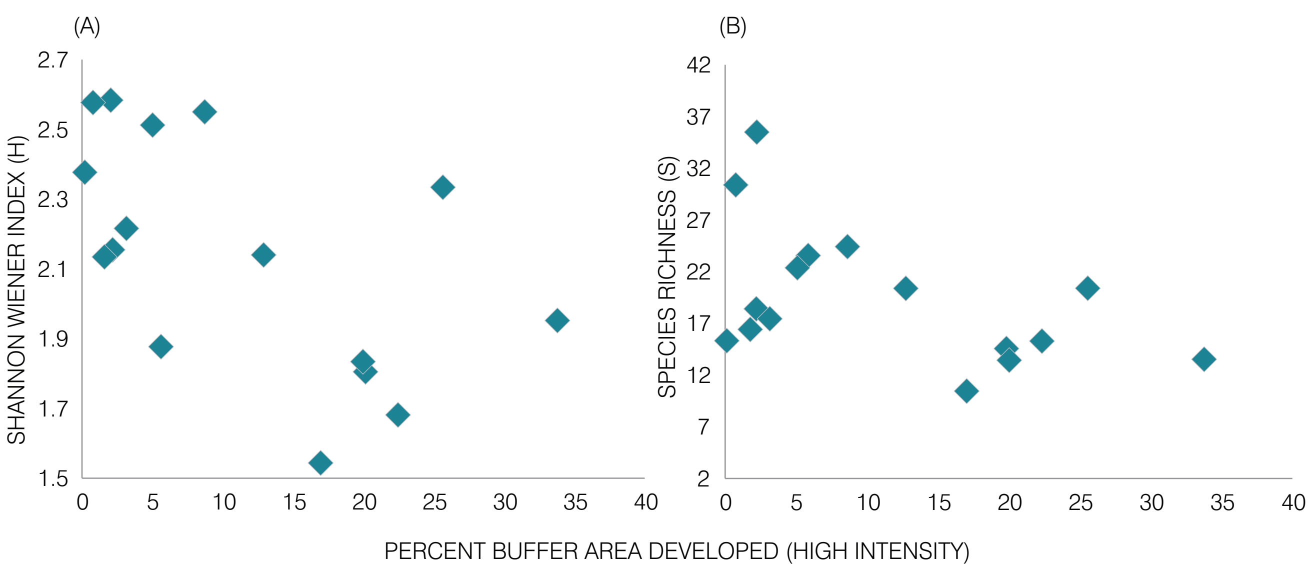

FIGURE 9 The proportion of high-intensity development in the 100-m buffer around tidal marshes related to marsh plant diversity as measured by (A) the Shannon-Wiener Index and (B) species richness.

(Silliman and Bertness 2004, Fitch et al. 2009). Although the marsh soil nitrate levels were relatively low and there is no cause for concern at this time, we should continue to monitor the possible effects of shoreline development and nitrogen inputs on the Saco Estuary. The results from this study provide a baseline dataset for this monitoring.

CONCLUSIONS

We made the following conclusions from our research on the plant communities in the Saco Estuary's tidal marshes:

- The tidal marshes contain a rich diversity of plant species growing in saltwater, brackish, and tidal freshwater marshes.
- Plant community diversity in the marshes is influenced by a number of factors, including salinity, distance to the river mouth, and the intensity of development in the adjacent shoreline.
- At least 10 rare plants grow in the marshes. Eight of these are Species of Concern and two are Threatened in the State of Maine.
- The invasive common reed, *Phragmites australis,* is found in both large- and small-sized patches in the marshes. A management plan for this species is needed to prevent it from spreading further.

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CHAPTER 4

BENTHIC MACROINVERTEBRATES OF THE SACO ESTUARY

TIDAL FLATS AND LOW MARSH HABITATS

BY ANNA L. BASS

INTRODUCTION

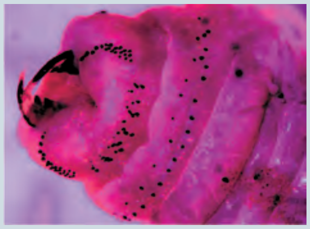
Why study invertebrates?

Invertebrates are an important food source for many birds and fish that live in estuaries. Common estuarine invertebrates include amphipods (*Gammarus*), bivalves (*Pisidium*), gastropods (Hydrobiidae), and polychaetes (*Hediste diversicolor*). Information on benthic invertebrate community composition in an estuary's marshes and mudflats can be used to indicate the healthy functioning of an estuary and its marshes.

Invertebrates, with their varying levels of tolerance to disturbance and pollution, have long been used as biological indicators of marsh health (Pearson & Rosenberg, 1978; Diaz, 1989; Warren et al. 2002; Hering et al. 2006). Land use and associated activities can significantly shape benthic invertebrate communities (Lerberg et al. 2000; Canedo-Arguelles et al. 2014). While human activities can significantly affect the abundance and types of invertebrates present, environmental factors also play a key role in structuring invertebrate communities. However, distinguishing between human and environmental impacts can be a challenge. Environmental factors that regulate the distribution and abundance of invertebrates in estuaries include (but are not limited to) sediment characteristics, salinity gradients, biomass of emergent vegetation, and predator presence (Chester et al. 1983; Ysebaert et al. 1998; Kang and King 2012; Yozzo and Osgood, 2013).

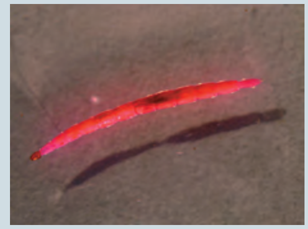
As one moves from the mouth of the Saco River to the Cataract Dam, the tidal marshes exhibit a salinity transition from polyhaline (18-30 ppt) to mesohaline (5–18 ppt) to oligohaline (0.5-5 ppt) and tidal freshwater conditions. In general, benthic invertebrate community composition shifts with polyhaline conditions, supporting communities dominated by polychaetes and crustaceans, and mesohaline conditions resulting in oligochaete and insect larvae-dominated communities (Yozzo and Osgood 2013).

Hydrobiidae



Hediste diversicolor

Oligochaete



Ceratopogonidae

Note: Organisms are stained with Rose Bengal to aid in recovery from the original core sample. Photos by Anna Bass.

Sampling invertebrates in the Saco Estuary's tidal marshes and mudflats.
Photos by Carrie Byron.

What is known about the invertebrates of the Saco Estuary?

This is the first study of its kind to document the invertebrate species in the estuary's tidal marshes and mudflats. Little to no information has been available on the types and numbers of infaunal (i.e., within the sediment) invertebrates that inhabit the tidal marshes of the Saco Estuary. Most studies that have included invertebrates have concentrated on areas near the mouth of the river that are dredging sites for the U.S. Army Corps of Engineers (USACoE 2013) or on highly mobile macrofauna (Reynolds and Casterlin 1985). The areas surveyed near the mouth of the river are affected by the inflow of salty water from Saco Bay and, consequently, are dominated by marine invertebrates (USACoE 2013).

STUDY OBJECTIVES—MACROINVERTEBRATES

The objectives of this macroinvertebrate study were to answer the following questions:

1. What types of invertebrates inhabit the tidal flats and low marsh habitats of the Saco Estuary?
2. How diverse are the invertebrate communities in the tidal flats and low marsh habitats?
3. Do invertebrate communities change as one moves down the Saco Estuary to the bay?

RESEARCH DESIGN AND METHODS

To answer these questions, multiple core samples were taken from areas located relatively close to the low tide line ($\leq$100 m). These core samples facilitated the collection of the top 4 cm of sediment in areas with plants such as *Spartina alterniflora* and the adjacent tidal flats. All sites were sampled within $\pm$1.5 hr of low tide. Six marshes were sampled once per month from May to August during 2013. The six marshes span the area from the Cataract Dam (N2 and S1) to the mouth of the river (N10 and S11), with two sites (N4 and S6) located in the middle reaches of the river (see Figure 1 for site locations). These sites were selected to capture the range of salinities observed along the river and to sample a broad range of invertebrate communities.

In addition to the core samples, we collected salinity data for the core samples, allowing us to document the salinity of the water present in the flats and in the vegetation.

RESULTS AND DISCUSSION

Salinity in the upper estuary sites (N2, S1, N4, and S6) ranged from 3.4–10.6 ppt for the tidal flat habitats and 3.4–10.6 ppt for the low marsh habitats. Salinity in the lower estuary sites (N10, S11) ranged from 16.3-26.2 ppt for the tidal flat habitats and 10.3–20.9 ppt for the low marsh habitats. N4 and S6 exhibited the higher end of the salinity ranges for both habitats during the May sampling periods; otherwise, the salinity values were more closely related to those found in all months for the N2 and S1 sites.

FIGURE 1 Tidal marsh study sites along the Saco Estuary.

TABLE 1 List of invertebrate species identified from May to August 2013 sampling events of both tidal flats and low marsh habitats of the Saco Estuary.

Annelida	Arthropoda	Mollusca	Nematoda	Nemertea
Hirudinida	Arachnida	Bivalvia		Anopla
Erpobdellidae	Acariformes	Sphaeriidae		Lineidae
Erpobdella sp.	Insecta	*Pisidium* sp.		*Lineus ruber*
Glossiphoniidae	Chironomidae	Tellinidae		
Gloiobdella elongata	*Bezzia/Palpomyia* sp.	*Macoma balthica*		
Polychaeta	Ceratopogonidae	Gastropoda		
Ampharetidae	*Forcipomyia* sp.	Hydrobiidae		
Hobsonia florida	*Procladius* sp.	Lymnaeidae		
Nereididae	*Tanytarsus* sp.	*Fossaria* sp.		
Hediste diversicolor	Limnephilidae			
Sabellidae	Thaumaleidae			
Manayunkia sp.	Tipulidae			
Spionidae	*Tipula* sp.			
Polydora sp	Malacostraca			
Oligochaeta	Anthuridae			
Enchytraeidae	*Cyathura polita*			
Naididae	Gammaridae			
	Gammarus mucronatus			
	Melitidae			
	Maera danae			
	Talitridae			
	Leptocheliidae			
	Hageria rapax			

What types of invertebrates inhabit the tidal flats and low marsh habitats of the Saco Estuary?

A minimum of 19 species were positively identified during the four months that sampling was conducted, and a minimum of 24 families were represented during our survey (Table 1).[1] For the oligochaetes, a minimum of two families, Enchytraeidae and Naididae, are present in the estuary (samples identified by professional taxonomists with EcoAnalysts, Inc.). It is highly likely that other oligochaete families are also present, but they await further discovery. Consequently, all oligochaete individuals were lumped into one group, the Oligochaeta. All dipterans were identified to family for this study, with some specimens identified to genera by professional taxonomists.

The most abundant members of the communities were the oligochaete worms, chironomid fly larvae, nereid worms, hydrobid snails, and ceratopogonid fly larvae, respectively (Table 2). Invertebrate abundance increased from lower salinity sites to higher salinity sites (west to east or down the estuary toward Saco Bay).

[1] The invertebrate data give a preliminary picture of the species present in the estuary and are limited in three ways. First, only a fraction of the marsh was sampled, i.e., the low marsh and tidal flats. Second, not all specimens were identified to species; therefore, all diversity and community level analyses were based on the family level. Third, this report includes data for only one year; therefore, yearly trend analysis is not possible.

TABLE 2 Mean abundance of invertebrates (no. individuals/m²) for the habitats within the six sites sampled. The abundance of three replicates in each of the two habitats was used to generate a mean over the four sampling periods: May, June, July, and August.

		N2		S1		N4		S6		N10		S11	
		Flat	Low	Flat	Low	Flat	Low	Flat	Low	Flat	Low	Flat	Low
Annelida													
Hirudinida									1				
	Erpobdellidae		3										
	Glossiphoniidae		15										
Polychaeta	Ampharetidae					3		13					
	Nereididae							15	3	72	111	261	
	Sabellidae							4					28
	Spionidae									11	11	1	
Oligochaeta		32	215	160	89	59	265	127	823	484	736	41	1776
Arthropoda													
Arachnida	Acariformes												1
Insecta	Ceratopogonidae	1	1	5	32	1	8	15	94		7		75
	Chironomidae	62	39	33	16	177	51	36	29				
	Limnephilidae	1											
	Siphloneuridae					1							
	Thaumaleidae					12					1		
	Tipulidae						1						
Malacostraca	Anthuridae					32	9	48					
	Gammaridae	1	11					1					
	Melitidae					3	1				5		1
	Talitridae										3		
	Leptocheliidae										9		
Mollusca													
Bivalvia	Sphaeriidae		41	3	1								
	Tellinidae									3			
Gastropoda	Hydrobiidae	7	44	12	29	17	237		3				
	Lymnaeidae		1			1	7						
Nematoda				3	8	3	1	1	3	3	7		5
Nemertea	Lineidae									1	1		
	Totals by Habitat	104	370	216	175	309	580	260	956	574	891	303	1886
	Totals by Site	474		391		889		1216		1465		2189	

How diverse are the invertebrate communities in the tidal flats and low marsh habitats?

To estimate the diversity of invertebrates for the various habitats and sites, Shannon-Wiener diversity indices based on family-level diversity were calculated (Figure 2). Diversity estimates were similar in both habitats, with tidal flats exhibiting a range of 0.9–2.0 and the low marsh habitats ranging from 1.1–2.1. Site N4 had the highest diversity value for the tidal flats, and N10 for the low marsh habitat.

Do invertebrate communities change as one moves down the Saco Estuary to the bay?

Many factors can influence where estuarine invertebrates live, including sediment characteristics and salinity. To determine whether the invertebrate communities differed according to where they were found in the Saco Estuary, we analyzed the data in two different ways. First, a nested permutational MANOVA (PERMANOVA) was applied to the community abundance data to assess whether multiple variables were significantly associated with the invertebrate communities at each site. Each habitat type was analyzed separately because tidal flats and low marsh habitats differ from each other. Variables included in the tidal flat analysis included the position (i.e., Biddeford or Saco side), porewater salinity, and sediment grain size, with the month sampling occurred nested. Neither position nor grain size had a significant effect on the community composition, but porewater salinity did ($Pr>F=0.001$, $p=0.001$).

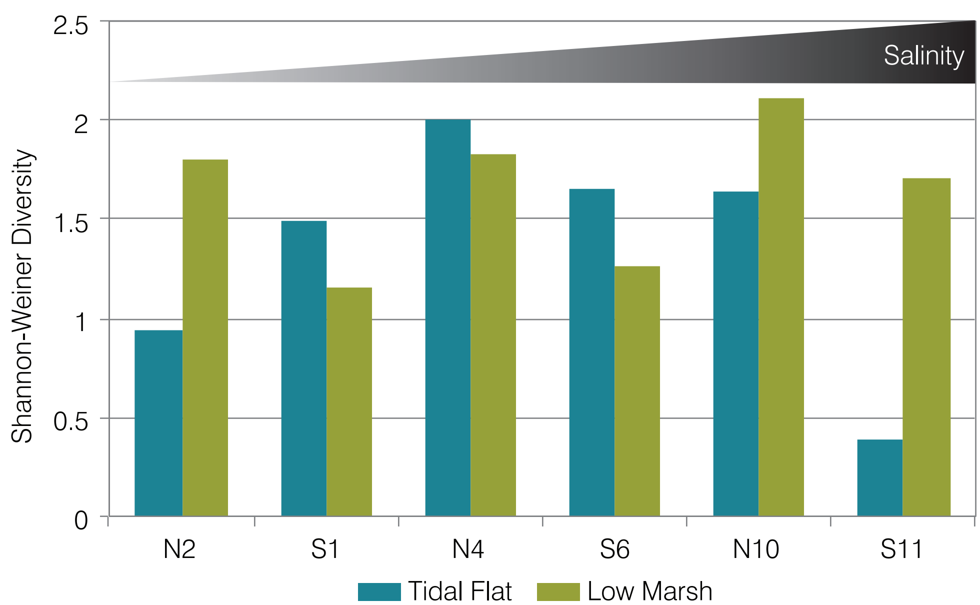
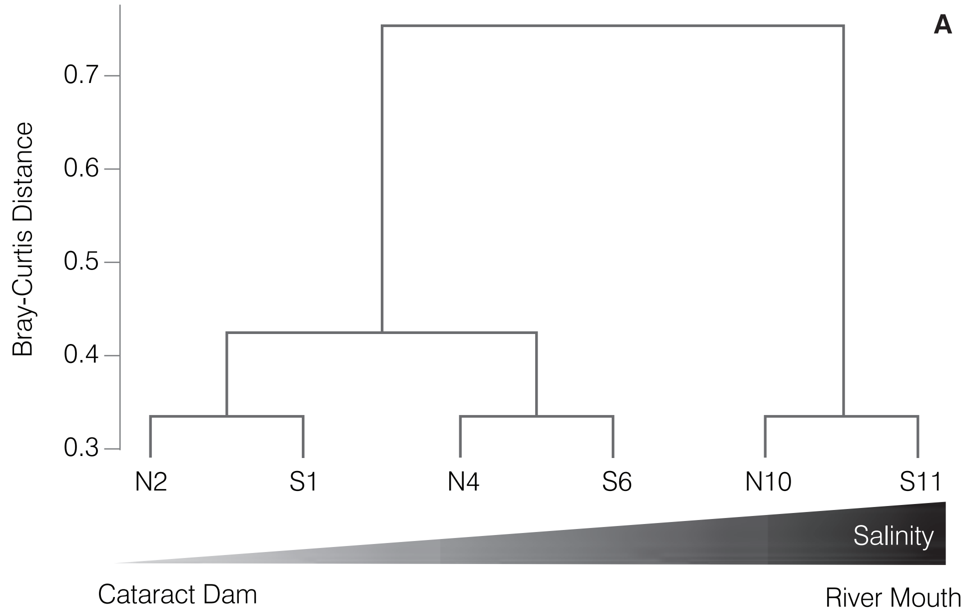


FIGURE 2 Invertebrate diversity by site and habitat as measured by the Shannon-Wiener Diversity Index. Abundance data for all months were averaged and standardized, and overall family-level diversity estimates were generated.



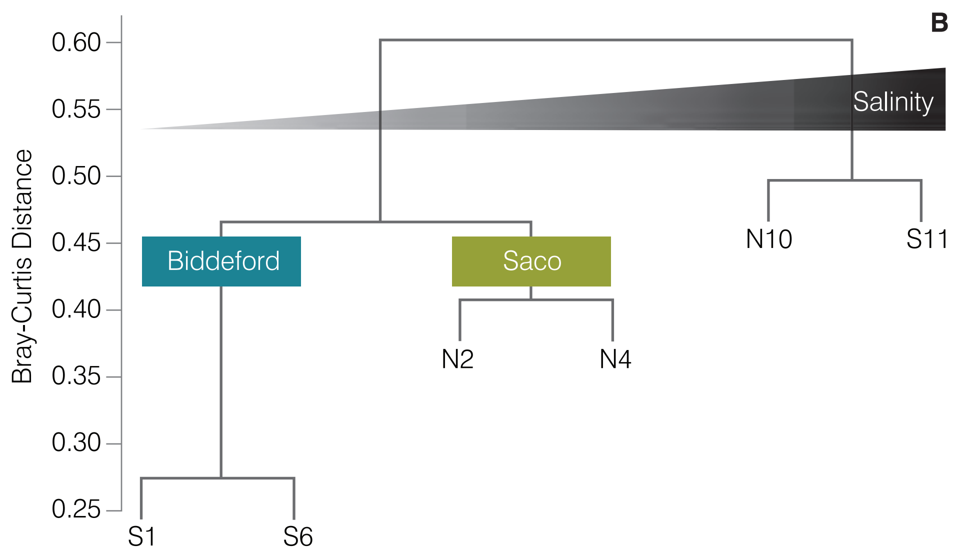


FIGURE 3 Cluster dendrogram for the tidal flat (A) and low marsh (B) invertebrate community data. Mean abundance data were converted to presence/absence data, and Bray-Curtis distances between each site were generated. Clustering was based on average distances among sites. (A) The impact of salinity is visible in the clustering of tidal flat communities with lower to intermediate salinity values (N2 & S1, N4 & S6, respectively) versus the higher salinity sites (N10 & S11). The transition from low salinity (near Cataract Dam) to high salinity (near the mouth of the river) is indicated by the blue triangle below the dendrogram. (B) Both the positional and salinity effects are recovered in the cluster analysis with Biddeford sites (S1 & S6) and Saco sites (N2 & N4) grouping together and the higher salinity sites (N10 & S11) forming a separate cluster. The level at which salinity is a significant factor is indicated by the blue bars and within the lower salinity sites, position as a significant factor is indicated by the clustering of the two Biddeford sites versus the Saco sites.

For the low marsh habitats, grain size of sediment was not available; therefore, the variables used in the model were position and salinity with month nested. The data analysis indicated that both position and salinity had significant effects on community composition (Pr>F=0.002 and p=0.01; Pr>F=0.007 and p=0.01, respectively), but no significant interactions between the two variables were indicated (Pr>F=0.130).

To determine whether there were clusters of sites based on community composition or types of invertebrates found at each site and within each habitat, a second approach, hierarchical clustering analysis with Bray-Curtis distances, was employed. For this analysis, the individual count data per site and habitats were standardized to presence/absence counts. Examination of the clustering analysis supports the nested PERMANOVA results, which indicated that salinity is a significant factor in the determination of the community composition of the tidal flats and both position and salinity are significant factors in the low marsh habitats.

CONCLUSIONS

Although more surveys are needed, and future identification of invertebrates in the Saco Estuary to the species level is necessary, the patterns we observed are consistent with what is known about the community ecology of benthic invertebrates in tidal marshes.

1. Different factors are important in determining the community composition of invertebrates in tidal flats versus the low marsh habitats. In the tidal flats, porewater salinity appears to play a significant role in community composition. In the low marsh habitats, multiple influences shape community composition including site location (Biddeford or Saco side) and porewater salinity. The significant effect of site location on low marsh communities may be tied to land use patterns or hydrodynamics of the river.
2. Other variables, such as land use patterns, contaminants, and plant community composition, likely play a significant role in structuring the invertebrate communities in both habitats and should be investigated.

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CHAPTER 5

FISH OF THE SACO ESTUARY

RIVER CHANNEL AND TIDAL MARSHES

BY KAYLA SMITH, KRISTIN WILSON, JAMES SULIKOWSKI, and JACOB AMAN

INTRODUCTION

Before the current study, what did we know about the fish using the Saco estuary?

A report published 30 years ago documented 18 fish species and a variety of crustaceans, echinoderms, and mollusks using the estuary (Reynolds and Casterlin 1985). A two-year survey conducted by UNE scientists in 2007 and 2008 using plankton tow nets, a seine net, and otter and beam trawls found 31 fish species in the estuary and in Saco Bay, just outside the river (Furey and Sulikowski 2011; Wargo et al. 2009). Nearly all of the species were observed at juvenile lengths (10 larval and 21 juvenile fishes), characterizing the system as a nursery ground.

The incidental capture of two Atlantic sturgeon by Furey and Sulikowski (2011) spurred an ongoing investigation into the ecology and movement of this important and threatened species in the estuary. Little et al. (2013) suggested that the Saco estuary is a foraging stopover site for migratory fishes such as the endangered shortnose sturgeon and the threatened Atlantic sturgeon (Figure 1).

These previous studies were limited to sampling fish just offshore in Saco Bay and close to the mouth of the river in the river channel. For the current study, fishing efforts in the river channel were extended up river to Cataract Dam and also included fishing on the surfaces of tidal marshes at high tide.

STUDY OBJECTIVES—FISH

The objectives of this study were to answer several questions about the fish in the estuary:

1. What additional fish species use the Saco estuary upriver from the mouth of the river?
2. Do the fish communities change as one moves from the mouth of the river up to Cataract Dam?

FIGURE 1 James Sulikowski, left, and student researchers pose with an Atlantic sturgeon measuring seven feet and one inch long before releasing it back into the Saco River.

3. Is there a difference in the types of fish using the river channel and the tidal marshes?
4. What commercially and recreationally important fish use the estuary?
5. Which species listed as threatened or endangered, or as species of concern, are found in the estuary?

RESEARCH DESIGN AND METHODS

We used four methods of sampling fish species in the Saco estuary to collect data on species composition, distribution, and abundance. Over four field seasons (2010–2013), we conducted beach seining near the river mouth, gillnetting and plankton tows (for larval fish) in the mid channel, and fyke netting on the marsh surface.

River Channel Sampling

Sampling using beach seines occurred at the mouth of the Saco River (at Freddy Beach) two or three times per week from March to November. Weekly gillnet surveys were conducted from June to September at three distinct locations: close to the river mouth, in the middle of the estuary, and below Cataract Dam. Gillnets are a passive

Species of Concern are those species about which NOAA's National Marine Fisheries Service (NMFS) has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act (ESA). "Species of concern" status does not carry any procedural or substantive protections under the ESA. *Source: NOAA.*

FIGURE 2 Map of river channel sampling sites from 2010–2013. Upper, middle, and lower are sites where gillnets were set. Beach seining was conducted at Freddy Beach.

gear type, meaning only fish actively swimming in the water column will be caught. Beach seine nets are an active gear type, catching mostly juvenile fish resting on or in sediments as well as in the water column. Sampling was performed during summer months when the estuarine fish community is the most representative of its composition and when the greatest contrast would be observed between sampling locations. Fish metrics recorded for samples from the seine and gillnets included total length for all species. In addition, we used a fish measuring board, tape measure, or calipers to measure fork length, head length, interorbital width, and mouth width of sturgeon species. Length measurements were recorded for the first 30 individuals of each species, with bulk counts recorded for all remaining individuals. For individuals captured during each sampling event, catch-per-unit-effort was calculated, and these values were then used to determine the percent of catch.

Surface plankton tows were also performed to collect larval fish (i.e., ichthyoplankton) at multiple locations within the estuary, between the upper and lower gillnet sampling sites. In 2010 and 2011, ichthyoplankton tows were performed biweekly in June through August. In 2012 and 2013, tows were conducted weekly in June through August, increasing sampling effort. A plankton net was towed with the UNE research vessel *Llyr* at a speed of approximately 2.0 knots for 10 minutes (Figure 4). Following collection, the plankton net was washed down to ensure that

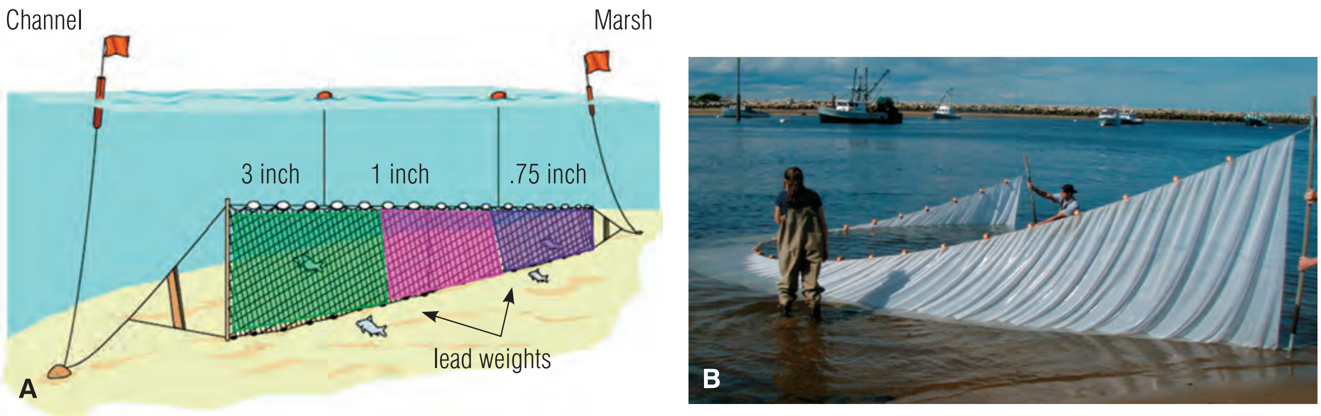


FIGURE 3 (A) Diagram of the multi-mesh gillnets used for sampling the river channel. *Image courtesy of Michigan Sea Grant.* (B) Beach seine used to sample the river channel along Freddy Beach.

FIGURE 4 Plankton tow net used to collect larval fish at multiple locations within the Saco estuary.

all specimens were in the cod end, and samples were preserved. Ichthyoplankton samples were sorted by hand using a dissecting microscope. Larval fish were measured, and key morphological characteristics were noted, including pigmentation patterns and fin ray and myomere counts for identification purposes.

Tidal Marsh Sampling

Many fish move onto the marsh surface at high tide, seeking food, shelter, and protection from predators. To sample under these conditions, fyke nets are used to sample fish species on the marsh surface when it is flooded by high tides (Figure 5). The nets also catch crustaceans such as crabs and shrimp. The fish and crustaceans caught are referred to as nekton.

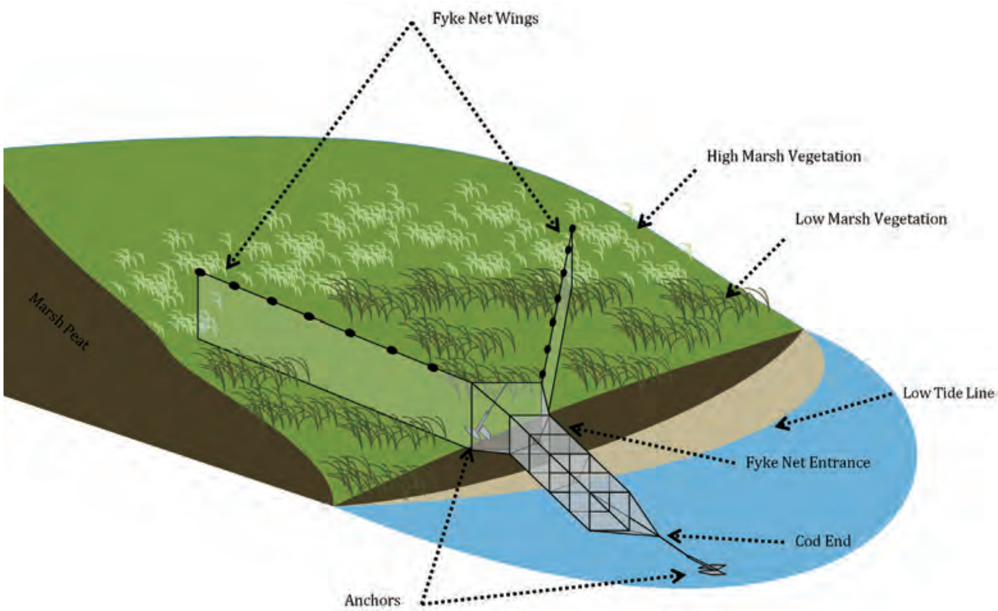


FIGURE 5 Fyke net deployment for sampling in tidal fringing marshes.

Eight of the 16 tidal marsh study sites were chosen for fish sampling (Figure 6). These eight were selected based on several criteria, including proximity to large areas of tidal marsh vegetation and suitability for use of fyke nets. We also selected sites so they were distributed from Cataract Dam to the river mouth, and so they reflected a range of development intensity in the adjacent upland. Some adjustments were made to the sites fished between 2010 and 2011 due to steep slopes and other issues that made sampling with fyke nets challenging. Sites were fished during one daytime and one nighttime high tide in August 2011, 2012, and 2013. In 2010, the sampling effort was greater, as each site was fished in both June and at the end of July.

Fish and crustaceans were identified to the species level, weighed, and measured. Bulk count and weight were recorded for all remaining individuals after the first 30 of each species. The distance between the fyke net and the flagged high tide line was measured so that the area fished could be calculated, allowing us to quantify the density of fish using the marsh surface.

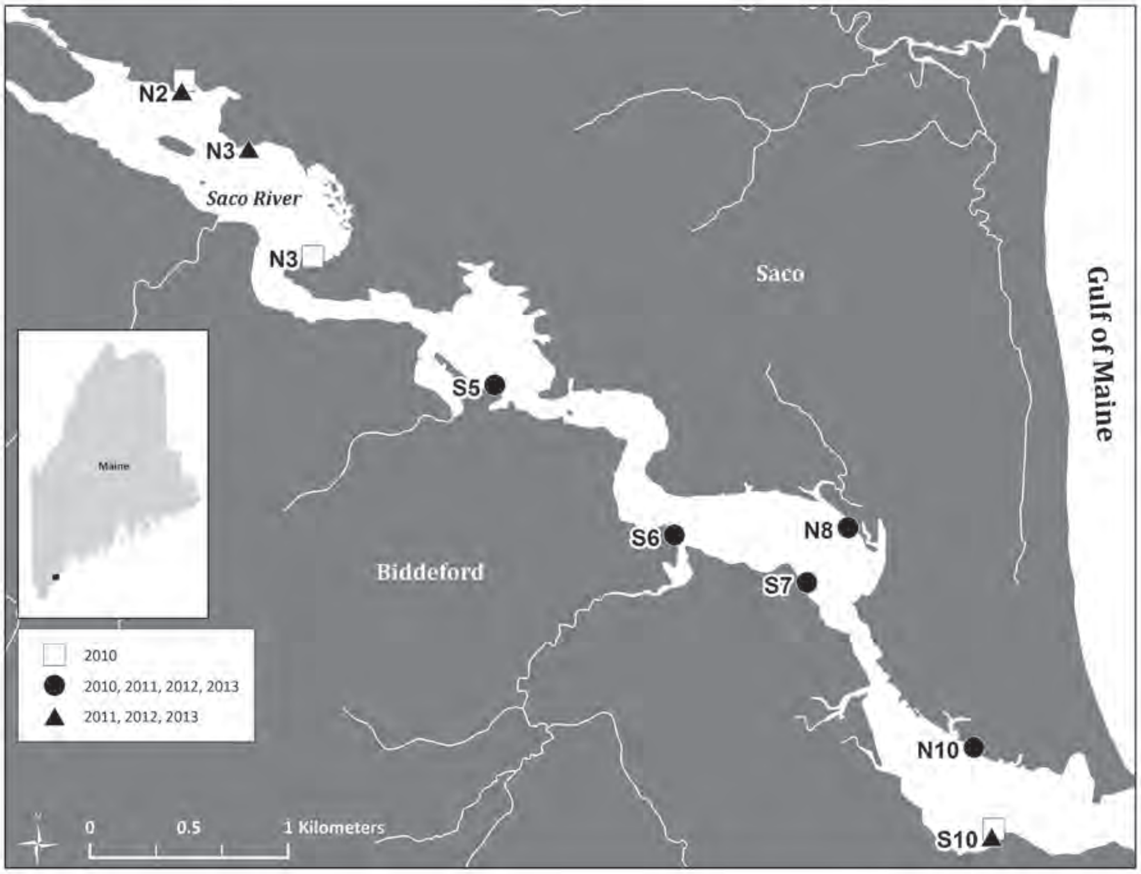


FIGURE 6 Map of tidal marsh fyke net sampling sites from 2010–2013.

RESULTS AND DISCUSSION

What did we learn about the fish of the Saco estuary?

There are more kinds of fish using the estuary than previously recorded.

This study resulted in the addition of 15 new species of juvenile and adult fish recorded for the Saco estuary, compared to the 24 species reported by Furey and Sulikowski (2011), the most comprehensive study until now. The 15 newly recorded species are bluegill, chain pickerel, golden shiner, lake chub, pollock, white sucker, American shad, Atlantic menhaden, longhorn sculpin, shortnose sturgeon, smallmouth bass, spottail shiner, striped bass, striped killifish, summer flounder, and white perch. Many of these new species recordings are of freshwater species using fringing marshes in the upper reaches of the estuary.

The Saco estuary has more fish than any other estuary documented in the State of Maine.

In this four-year study, 39 species were identified using the river channel and the tidal marshes (Table 1). Combined with previous studies, the total number of fish species using the estuary stands at 41. Adding those species caught in nearby Saco Bay (29) gives us a total of 64 species of fish documented using the estuary and the waters outside the river mouth.

Most of the same fish species use the river channel and the tidal marshes.

TABLE 1 The 39 fish species of the Saco estuary caught in the river channel and the marsh surface from 2010-2013 with sampling method and life history. Life history categories include: d = diadromous, m = marine, e = estuarine, f = freshwater (from FishBase v. 04/2014).

			River Channel Sampling		Tidal Marsh Sampling
Scientific Name	Common Name	Life History Classification	Beach Seine	Gill net	Fyke net
Alosa pseudoharengus	alewife	d	X	X	X
Anguilla rostrata	American eel	d	X	X	X
Ammodytes americanus	American sand lance	m	X		
Alosa sapidissima	American shad	d		X	
Clupea harengus	Atlantic herring	m	X	X	X
Brevarotia tryanous	Atlantic menhaden	m	X	X	
Menidia menidia	Atlantic silverside	m	X		X
Acipenser oxyrinchus	Atlantic sturgeon	d		X	
Microgadus tomcod	Atlantic tomcod	d	X	X	X
Fundulus diaphanus	banded killifish	e	X		X
Alosa aestivalis	blueback herring	d	X	X	X
Pomatomus saltatrix	bluefish	m	X	X	X
Lepomis macrochirus	bluegill	f			X
Esox niger	chain pickerel	f			X
Apeltes quadracus	fourspine stickleback	f	X		X
Notemigonus crysoleucas	golden shiner	f			X
Couesius plumbeus	lake chub	f			X
Micropterus salmoides	largemouth bass	f	X		X
Fundulus heteroclitus	mummichog	e	X		X
Pungitius pungitius	ninespine stickleback	e	X		
Syngnathus fuscus	northern pipefish	m	X		X
Pollachius virens	pollock	m			X
Lepomis gibbosus	pumpkinseed	f	X		X
Osmersus mordax	rainbow smelt	f	X		X
Urophycis chuss	red hake	m	X		X
Myoxocephalus octodecimspinosus	longhorn sculpin	m	X		
Acipenser brevirostrum	shortnose sturgeon	d		X	
Micropterus dolomieu	smallmouth bass	f	X		
Notropis hudsonius	spottail shiner	f	X	X	X
Morone saxatilis	striped bass	d	X	X	
Fundulus majalis	striped killifish	e	X		X
Mugil cephalus	striped mullet	m	X		
Paralichthys dentatus	summer flounder	m	X		
Gasterosteus aculeatus	threespine stickleback	e	X		X
Morone americana	white perch	f		X	X
Catostomus commersonii	white sucker	f			X
Scophthalmus aquosus	windowpane flounder	m	X		
Psuedopleuronectes americanus	winter flounder	m	X		X
Perca flavescens	yellow perch	f			X
Totals for sampling methods			28	13	27

Different gear types are needed to fully sample the range of fish diversity.

The gear types used were complementary, each yielding different information about fish communities in the estuary. Specifically, beach seining sampled eight species that were sampled by no other method (American sand lance, ninespine stickleback, longhorn sculpin, smallmouth bass, striped mullet, summer flounder, threespine stickleback, and windowpane flounder). Gill netting sampled three species that were sampled by no other method (American shad, Atlantic sturgeon, and shortnose sturgeon). Finally, fyke netting of fringing marshes revealed seven species that were sampled by no other method (bluegill, chain pickerel, golden shiner, lake chub, pollock, white sucker, and yellow perch). With the exception of pollock, all of these additional species sampled by fyke netting are freshwater species.

The fish species that are most common differ between the river channel and the tidal marshes.

River Channel Sampling

In the river channel, 32 fish and five crustacean species were caught between April 2010 and November 2013. Near the river mouth, American sand lance and Atlantic herring were among the most abundant species collected using the beach seine (Figure 7). Atlantic herring is a schooling marine transient species that was observed in high abundance entering the estuary in both 2011 and 2012.

Tidal Marsh Sampling

Fyke netting of the marshes from 2010-2013 captured 27 fish species and two crustacean species. The total number of individuals caught varied greatly across years and sites. Eight species (American eel, blueback herring, European green crab, largemouth bass, mummichog, sand shrimp, striped killifish, and white perch) were caught in all four sampling years.

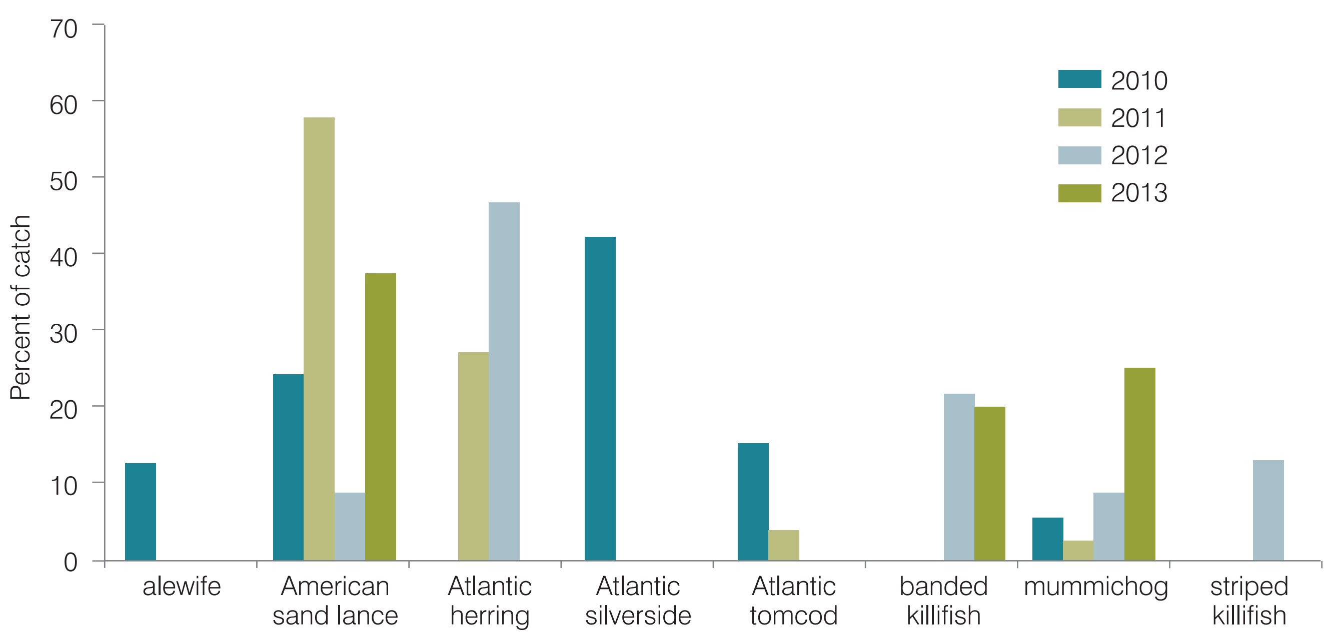
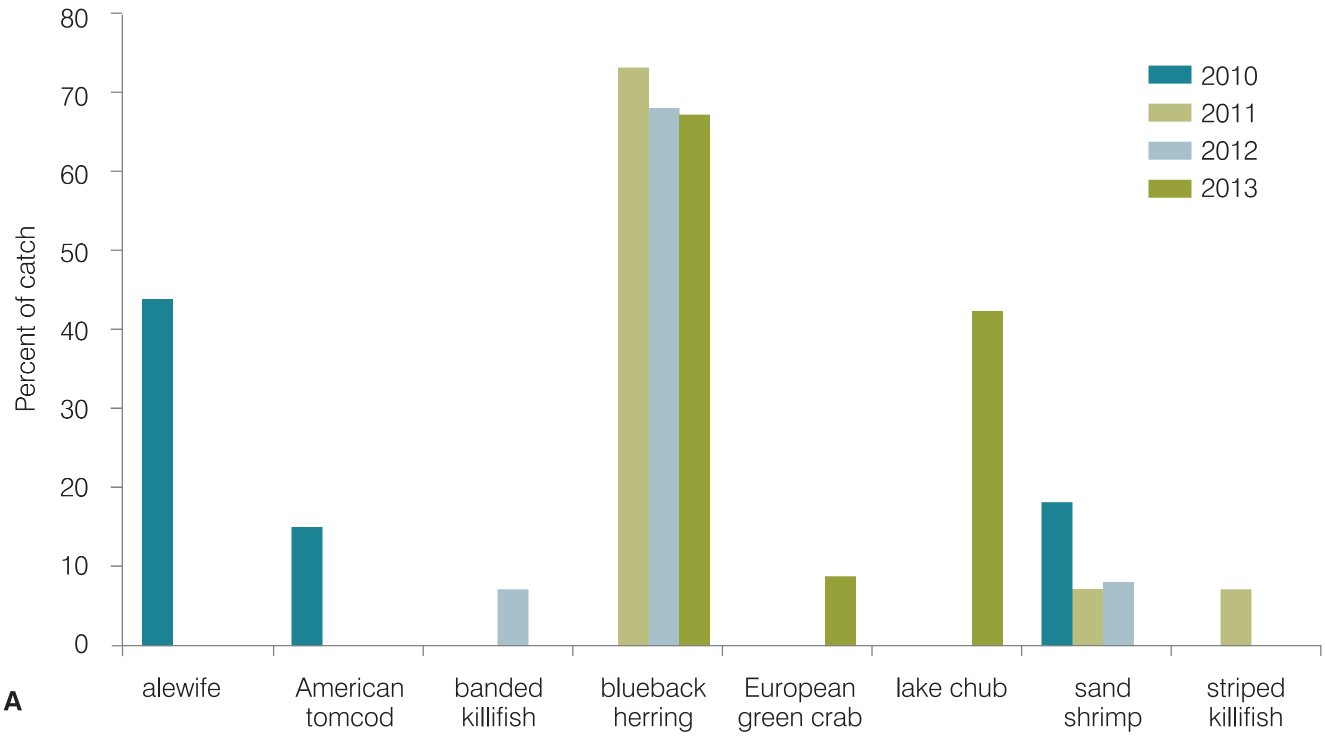


FIGURE 7 Most abundant fish species collected near the river mouth in beach seines.



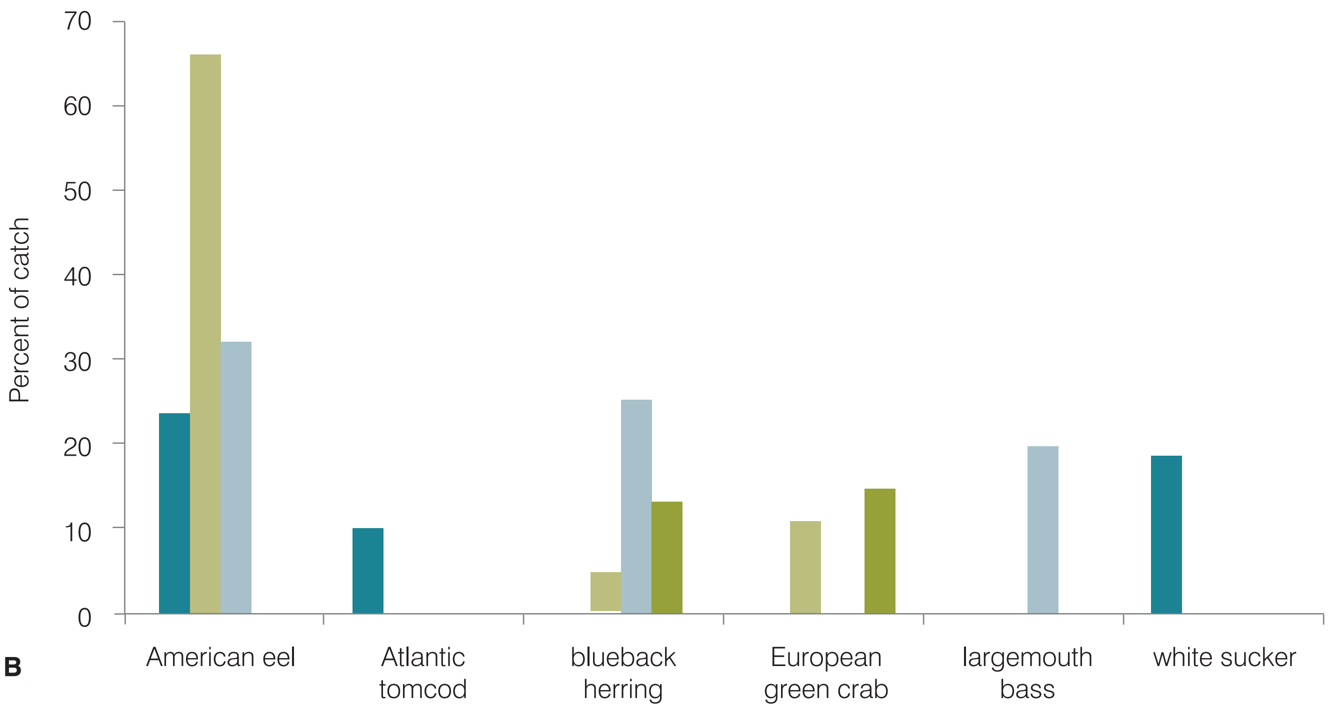


FIGURE 8 Fish and crustaceans using the tidal marshes. Shown are the top three species caught in fyke nets each year. (A) Most abundant species numerically. (B) Species sorted by biomass..

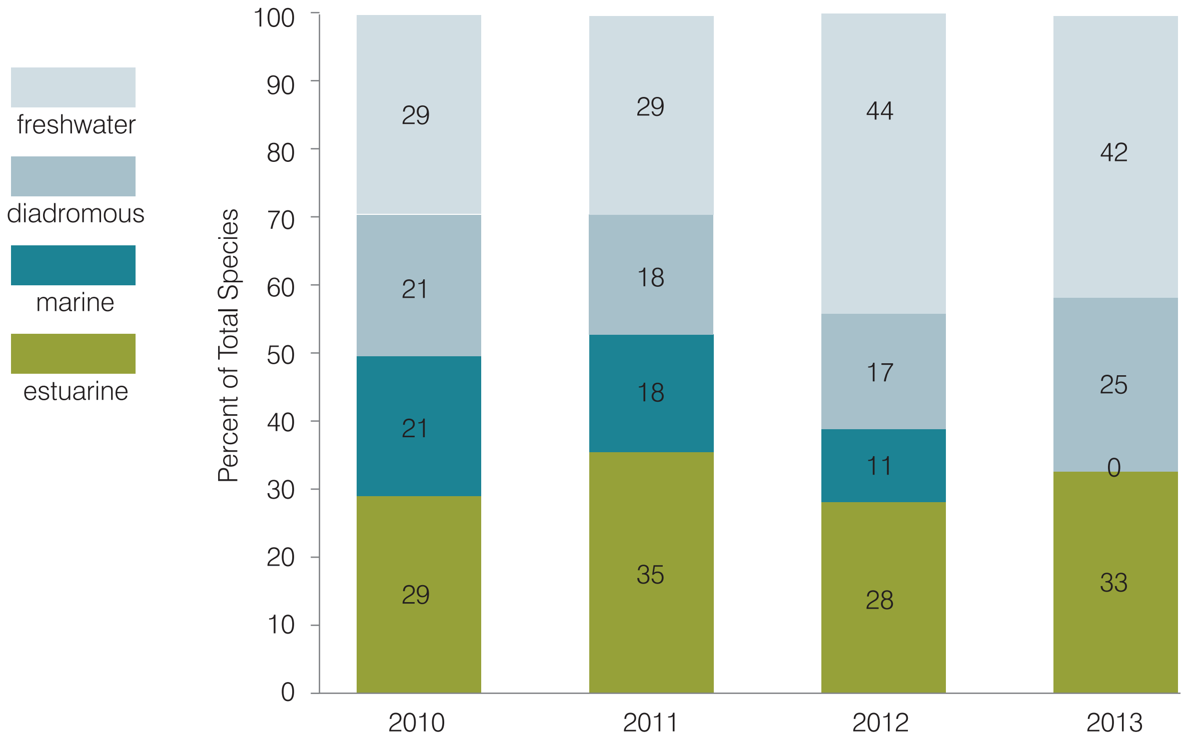


FIGURE 9 Percent of species caught fyke netting that represent each life history designation as categorized by Dionne et al. (1999) and FishBase v. 04/2014. Marsh resident species and freshwater species represented most of the total catch in every year sampled.

Blueback herring were caught in the greatest numbers in three of the four years (Figure 8). American eels were not as numerous, but due to their large size they comprised the greatest proportion of biomass every year. Other species numbers and biomass were more variable over time.

Also, most of the species using the tidal marshes were either marsh resident species or freshwater species (Figure 9). However year-round sampling would be needed to determine actual residency in the Saco River marshes.

Commercially and recreationally valuable species as well as federally listed endangered species, threatened species, and species of concern use the river channel and the tidal marshes.

Four fish species of recreational importance were caught. These species were largemouth bass, pumpkinseed, and bluefish (found in both the river channel and the tidal marshes) and the striped bass (caught in the river channel).

Three commercially valuable species were caught in the river channel and in the marshes (Atlantic herring, winter flounder, and red hake).

Two species listed under the Endangered Species Act were discovered using the estuary: the threatened Atlantic sturgeon and the endangered shortnose sturgeon (both found in the river channel). Also found were the alewife, blueback herring, and rainbow smelt, which are considered Species of Concern by NOAA's National Marine Fisheries Service. These species were caught in both the river channel and the tidal marshes.

Fish communities differ as one moves from the river mouth up to Cataract Dam.

Salinity gradients caused by freshwater runoff and tidal flushing were found to affect the distribution and abundance of fish species in the Saco estuary. The regulation of freshwater discharge by various hydroelectric dams along the river may also affect the movement of fish species within the estuary.

River Channel Sampling

The water at the bottom of the river channel was saltiest at the lower sampling site (17.1 ± 2.4 ppt), decreasing upriver at the middle (6.2 ± 1.9 ppt) and upper sites (5.7 ± 1.9 ppt). More marine fishes, such as the Atlantic herring and red hake, were caught at the sampling sites closest to the mouth of the river. Freshwater fishes, such as the spottail shiner and white perch, were more common at the two upper sampling sites.

The diversity of fish species as measured by species richness (S) and the Shannon-Wiener diversity index (H) varied across the river channel sites and with the method of sampling. Looking first at the sites sampled using gillnets, the number of species caught increased as we sampled farther upriver (3 at the lower sample site,
10 at the middle site, and 12 at the upper). Diversity as measured by the Shannon-Wiener Index (H) was greatest at the middle site (H=1.82), followed by the upper (H=1.23) and lower (H=1.03) sites. Sampling using the beach seine caught by far the greatest number of species (S=28; H=1.82).

Also, at the beach seine site near the mouth of the river, the salinity of the water during sampling affected the types of fish caught. Most of the catch contained freshwater species when the water was fresh to oligohaline (0–5 ppt). When the water was saltier, or mesohaline (5–18 ppt), more than half of the species caught were marine. Estuarine fish species were equally present in fresh and oligohaline as well as mesohaline water (Figure 10).

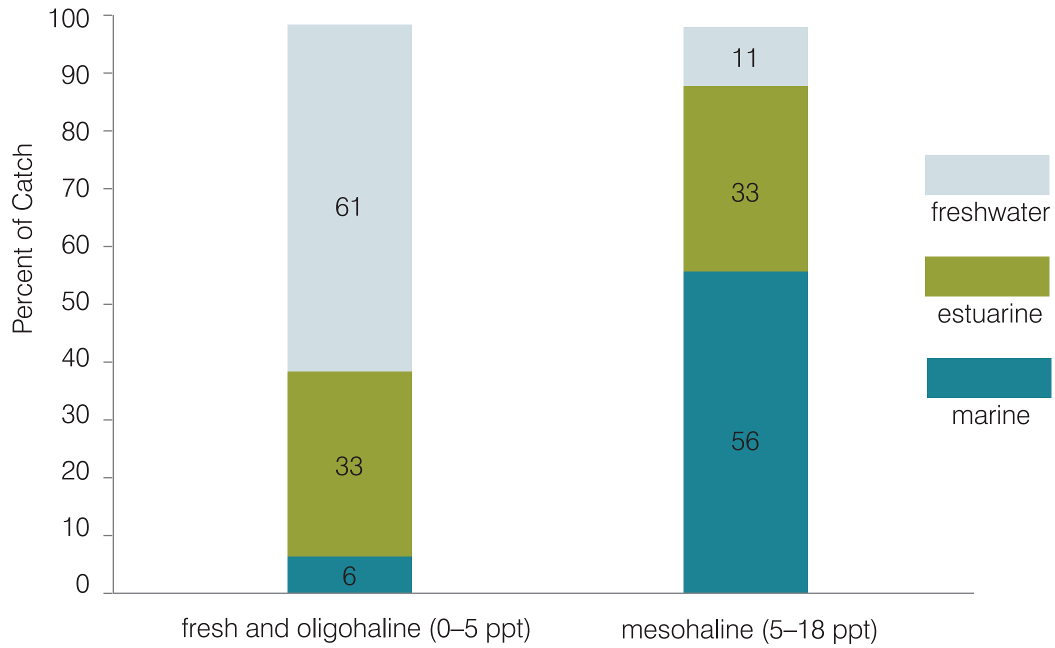


FIGURE 10 Distributions of freshwater, estuarine, and marine fish species between fresh and oligohaline (0–5 ppt) water and mesohaline (5–18 ppt) water during 2013 beach seine sampling. As only 4% of total catch in seines were diadromous (catadromous or anadromous), fish were put into marine or freshwater categories according to where they spend the majority of their lives (catadromous were considered freshwater and anadromous were considered marine). Fish species life history classifications categorized by Dionne et al. (1999) and FishBase v. 04/2014.

Tidal Marsh Sampling

Similar to the pattern observed in the river channel, the number of different species using the marsh surface increased with distance from the mouth of the river, due to more freshwater fish being caught upriver. This reflects the salinity gradient we observed from sampling the water on the marsh surface during fishing events (Figure 11) and agrees with other published studies (e.g., Fitzgerald et al. 2002). In contrast to the increase in species richness, we found that the total number of fish using the marshes decreased at the upper river sites.

In all years but one, site N2, which was located the farthest upriver, was the most diverse site as measured by the Shannon-Wiener diversity index (H) (Table 2).

Percent species composition by number of individuals and biomass reveals considerable variation across sites and across years for any one site (Figure 12). A shift in species composition seems to occur near site S5, with greater relative abundance of freshwater species occurring at that site and sites upriver (N3 and N2). The variability in species composition across sites and years demonstrates that multiple sampling efforts are needed to fully characterize fish communities using fringing marshes of the Saco estuary.

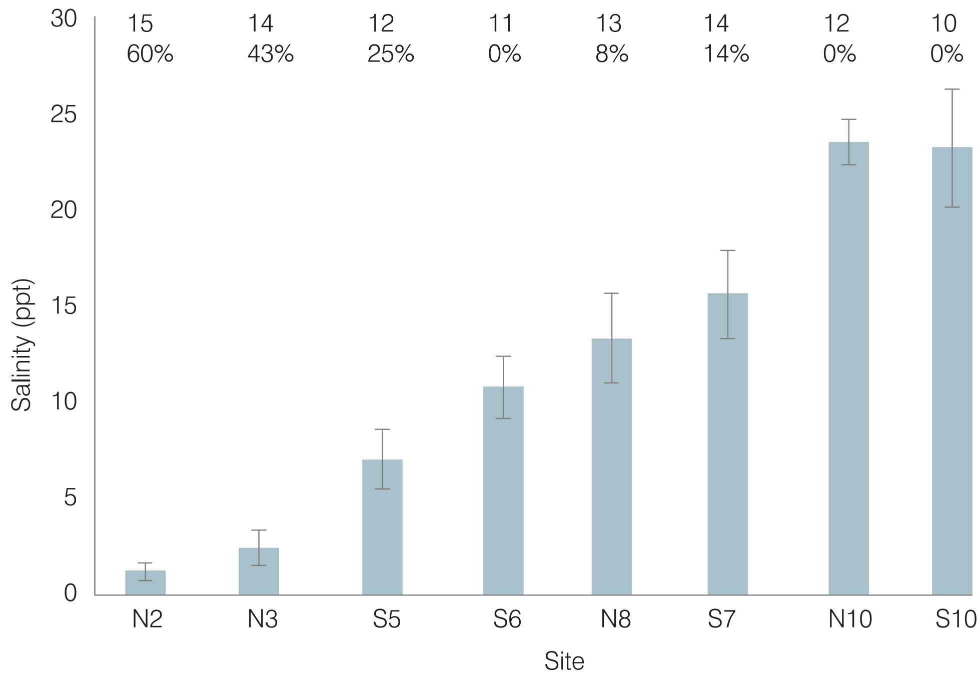


FIGURE 11 Average marsh surface water salinity (ppt) ± standard error, all years combined (2010–2013) from fyke net sampling. The number of fish species caught at each site and the percent of those that are freshwater species are given above each bar.

TABLE 2 Shannon-Wiener diversity index (H) by site and across years. The site with the greatest diversity each year is highlighted in red. Sites with the least diversity in a given year, indicated in blue, were more variable.

	Year			
Site	2010	2011	2012	2013
S10	1.13	1.29	0.00	1.05
N10	1.42	1.32	1.44	0.73
S7	1.20	1.62	0.52	1.29
N8	1.48	1.24	0.14	0.62
S6	1.32	1.03	0.64	0.59
S5	1.51	1.15	1.04	0.97
N3	1.46	0.46	1.29	1.17
N2	2.03	1.51	1.45	1.62

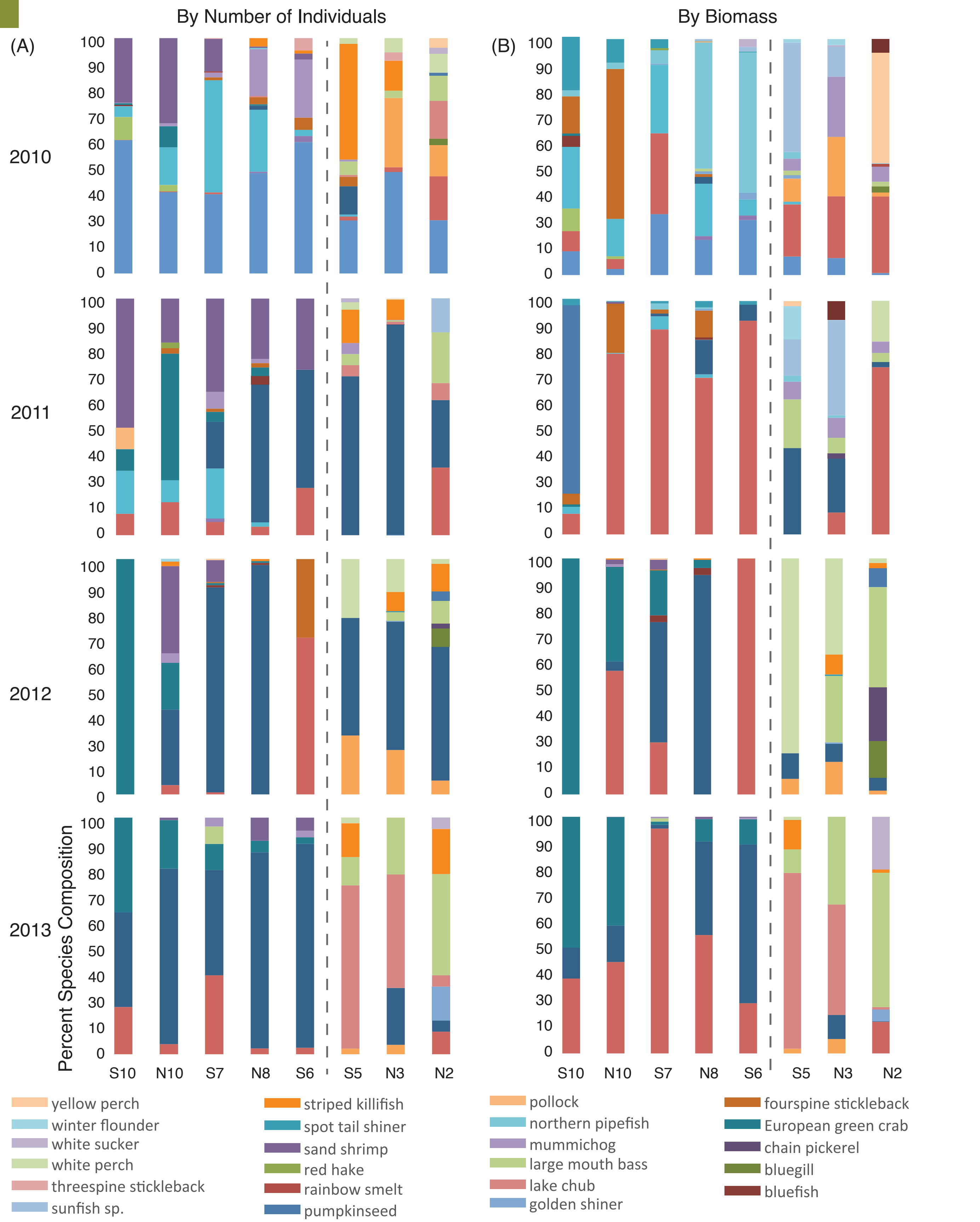


FIGURE 12 Percent species composition by site and year as determined by (A) number of individuals and (B) biomass.

The estuary is an important nursery ground for larval fish.

From the 64 ichthyoplankton tows conducted during this study, 586 larval fish representing at least 13 species were identified (Table 3). The overall abundance and total number of larval fish observed is considerably lower than in tows conducted in Saco Bay (Wargo et al. 2009; JA Sulikowski, unpublished data). Species diversity is difficult to characterize because 20% of the total catch is still unidentified. These larvae are presumably of freshwater taxa, which will require additional resources to positively identify. Approximately 75% of identified larvae were marine species. Of those larvae, northern pipefish and Atlantic herring were the most abundant species, representing approximately 65% of the total catch. Before this study, fourbeard rockling, mummichog, and spottail shiner larvae had not been observed in the Saco estuary. The collection of new larval fish species provides an impetus for further study of the estuary as a fish nursery ground.

TABLE 3 Compiled ichthyoplankton species list and total number of individuals collected from plankton tow sampling from 2010-2013 (all sites combined). Life history categories include: d = diadromous, m = marine, e = estuarine, f = freshwater (from FishBase v. 04/2014).

Scientific Name	Common Name	Life History Classification	% of Total Catch
Syngnathus fuscus	northern pipefish	m	45.6
Clupea harengus	Atlantic herring	m	19.8
Scophthalmus aquosus	windowpane flounder	m	7.7
Perca flavescens	yellow perch	f	1.7
Apeltes quadracus	fourspine stickleback	e	1.0
Tautogolabrus adspersus	cunner	m	0.9
Ammodytes americanus	American sandlance	m	0.7
Enchelyopus cimbrius	fourbeard rockling	m	0.3
Fundulus heteroclitus	mummichog	e	0.3
Notropis hudsonius	spottail shiner	f	0.3
Psuedopleuronectes americanus	winter flounder	m	0.2
Moronidae spp.	striped bass and white perch	e, d	10.1
Cluepeidae spp.	alewife, American shad or blueback herring	d	8.5
Unidentified			2.9

CONCLUSIONS

We make the following conclusions from our study of fishes in the river channel and tidal marshes of the Saco estuary.

- A surprising result was that both the Saco River channel and its fringing marshes are important habitats for many federally listed species of concern as well as commercially and recreationally important fish species. In addition, the Saco estuary supports the greatest fish diversity of any estuary within the Gulf of Maine with associated research that has been published in the peer-reviewed literature to date.
- Within the Saco estuary, we have now observed all but three of the 12 diadromous fish species known to occur in the Gulf of Maine. Diadromous fishes provide important links between rivers and the sea, migrating through estuarine systems as part of their life cycle. These fishes have served as economically valuable and culturally important resources for historical and present-day coastal communities in Maine. However, diadromous fish populations are at record low levels because access to spawning habitats has been impeded by dams and the commercial harvest was previously unregulated. Currently, little is known of these fish assemblages within small coastal rivers in Maine. Establishing a current diadromous fish population baseline within the estuary is essential for future conservation of these important fishes and associated marine resources.
- The results of this study suggest that fish communities of the Saco estuary are structured, in part, by the salinity gradient from the river mouth to Cataract Dam. Changing climatic conditions and land-use decisions may affect this gradient. Rising sea level, increased frequency and/or intensity of extreme precipitation and flooding events, and increased amounts of impervious surface within the shoreland zone and surrounding watersheds are all factors that will likely influence the structure of fish community assemblages in the Saco estuary spatially and temporally. Data collected during this study may provide one baseline by which future studies may compare fish community data.

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CHAPTER 6

BIRD COMMUNITY OF THE SACO ESTUARY

TIDAL MARSHES

BY NOAH PERLUT

INTRODUCTION

The Saco estuary separates the towns of Saco and Biddeford, Maine, and includes both tidal salt and tidal fresh marshes. Landscape factors affecting the tidal portion of the river have changed dramatically over the last century, including the closure of large industrial mills in the early 1970s, construction of numerous in-river jetties, and a land-use shift from agriculture to suburban development. To assess the impact of these changes on birds, we established a long-term study of bird diversity and abundance, as well as the ecological processes affecting these factors, in the tidal marshes on the Saco River. The status and composition of the bird diversity for this estuary had never been assessed prior to this study. Therefore, the drivers that affect ecological processes are unknown. The most recent comprehensive avian diversity study was done as a literature review and not field study by the U.S. Department of Agriculture in 1983. The USDA researchers identified 165 species of birds as occurring in the entire 385-square-mile Saco River watershed.

Tidal marsh bird diversity is affected by factors such as marsh size, proportion of invasive plant species, plant diversity, and salinity (Craig and Beal 1992; Shriver 2004; Xiaojing 2009). Here we hypothesize that marsh size and extent of invasion by non-native *Phragmites australis* would explain variation in marsh bird diversity. We studied the 16 small intertidal marshes ranging from tidal fresh to tidal salt (Figure 1). We classified the land cover—open fresh water, mud flat, forest, barren, developed, developed open, agriculture, and vegetated but not forest—within a 100 m buffer around each marsh (see Chapter 8), assessed the plant species diversity (see Chapter 3), and measured salinity (also described in Chapter 10), marsh area, and marsh proximity to the mouth of the river.

STUDY OBJECTIVES—BIRDS

Our objectives for the bird study were to answer these questions related to the tidal marshes of the Saco Estuary:

1. Which species of birds use the tidal marshes of the Saco Estuary?
2. Which bird species of concern use the estuary?
3. What are the landscape factors that influence bird diversity in the estuary?

RESEARCH DESIGN AND METHODS

We conducted 10-minute point counts in May through September 2010–2013 between sunrise and 9:45 a.m. at 16 sites. The 16 sampling sites were located on both the Biddeford and Saco sides of the river and ranged from 562 m (Camp Ellis) to 7,000 m (near Cataract Dam in Biddeford) from the mouth of the river (Figure 1). The average marsh size was 5.58 ha and the average marsh width was 81.2 m (Table 1).

Each bird was classified as less than 50 m, 50–100 m, or more than 100 m from the count site. We counted birds up to 10 m beyond the marsh edge, regardless of surrounding habitat type (Figure 2). The analysis includes only species that explicitly use marshes for some aspect of their life histories, and that were counted within 50 m of the point. The total species count includes all birds counted across all the distance classes.

We first calculated marsh bird diversity at each of the 16 marshes using the Shannon-Wiener Index. We then used these marsh-specific diversity values with an information theoretic approach (Burnham and Anderson 2002) to understand variation in marsh bird diversity. We used this approach to test the effects of plant

FIGURE 1 Locations of the 16 tidal marsh sites sampled along the Saco River. The center of the circles indicate the point count locations.

TABLE 1 Biotic and abiotic factors used to explain variation in marsh bird diversity in the Saco estuary.

Explanatory factors (range and mean)	
Plant species diversity (species richness): 11 – 35 (mean = 20)	
Salinity (ppt): 0.18 – 18.6 (mean = 8.4)	
Marsh area (ha): 0.2 – 19.1 (mean = 5.6)	
Marsh width (m): 9 – 200 (mean = 81.2)	
Distance to the mouth of the river (m): 478 - 7000 (mean = 3410.9)	
Total area of marsh occupied by *Phragmites australis*: 0 - 28.7% (mean = 2.6%)	
Percent of surrounding landscape	open, fresh water (0 – 1.2%)
	mudflat (0.3 – 19.5%)
	forest (0 – 67.8%)
	barren (0 – 5%)
	developed open (0 – 28.5%)
	developed (12 – 56.3%)
	agriculture (0 – 24.7%)
	vegetated, not forest (0 – 5.3%)

FIGURE 2 Tidal marshes on the Saco River are small and surrounded by diverse habitat types, increasing the overall diversity of bird species that use the marsh and its edges. We stood at the yellow marker during the point count at this site. Distance values are included to give context to the marsh size and proximity to other land cover types.

diversity, salinity, marsh size, marsh width, distance to the mouth of the river, and surrounding landscape characteristics on bird diversity by running a series of single factor, two- and three-way additive, and two-way interactive generalized linear models (Table 1). Competing models were ranked by their corrected (for small sample size) Akaike Information Criterion (AIC_c) values. AIC_c is a second-order correction for AIC computed as −2(log likelihood) − 2(the number of estimated parameters). We then calculated Δ for each model, which measures the difference in AIC_c between model *I* and the best-fitting model and the AIC_c weight (w_i), interpreted as the probability of being the best model in the model set. This allowed us to identify the characteristics that are most likely to affect variation in tidal marsh bird diversity.

RESULTS AND DISCUSSION

We identified 53 marsh bird species and 133 total bird species, representing 40.2% of all bird species known to occur in Maine (Table 2). We identified three state-listed endangered species, one listed threatened species, and 20 listed species of special concern.

The average number of plant species per marsh was 20, although this varied across marshes (Table 1). The land cover surrounding the marshes also varied notably among marshes. The land cover types that varied the most among the marshes included mudflat, forest, developed, developed open, and ag riculture. The cover types barren, open fresh water, and vegetated but not forest all showed less variability among sites (Table 1). The non-native plant *Phragmites australis* occupied 0-28.7% (mean = 2.6%) of the marsh plant cover and occurred in six of the 16 marsh study sites.

Variation in marsh bird diversity was best explained by salinity (Table 3; Figure 3) and percent cover of barren land around the marsh (Figure 4). Salinity was in the top three ranking models, which together explained 47% of the variation in marsh bird diversity. Barren was defined as 15% or less vegetative coverage, primarily shrubs and no mature tree species. Barren land cover was in two of the three top ranking models, which together explained 26% of the variation in bird diversity. Marsh size, plant species diversity, extent of invasion by *Phragmites*, marsh width, distance from the mouth of the river, and the proportion of other types of land cover did not explain variation in marsh bird diversity.

Factors Affecting Avian Diversity

Salinity was the most important factor influencing variation in marsh bird diversity in the tidal marshes of the Saco River. This result is particularly interesting in that the river's salinity is likely lower than it was pre-1900, as the numerous rock jetties in the river influence how salt water moves in the tidal portion of the river. Our results contradict other studies that showed mar should be viewed by managers with caution because the amount of barren land around these study marshes was very low (0-5% of the surrounding landscape). Therefore, it is possible this was a spurious result or that it masked the effects of some other unmeasured variable.

TABLE 2 Bird species identified in the tidal marshes or within 10 m of the marsh edge of the Saco River.

Scientific Name	Common Name	State Listing
Accipiter cooperii	Cooper's Hawk	
Accipiter striatus	Sharp-shinned Hawk	
Actitis macularius	Spotted Sandpiper	
Agelaius phoeniceus	Red-winged Blackbird	
Aix sponsa	Wood Duck	
Ammodramus caudacutus	Saltmarsh Sharp-tailed Sparrow	Species of Special Concern
Ammodramus nelsoni	Nelson's Sharp-tailed Sparrow	Species of Special Concern
Anas clypeata	Northern Shoveler	
Anas platyrhynchos	Mallard	
Anas rubripes	American Black Duck	
Anser anser domesticus	Domestic Goose	
Anthus rubescens	American Pipit	Endangered
Archilochus colubris	Ruby-throated Hummingbird	
Ardea alba	Great Egret	
Ardea herodias	Great Blue Heron	Species of Special Concern
Baeolophus bicolor	Eastern Tufted Titmouse	
Bombycilla cedrorum	Cedar Waxwing	
Branta canadensis	Canada Goose	
Buteo jamaicensis	Red-tailed Hawk	
Buteo platypterus	Broad-winged Hawk	
Butorides virescens	Green Heron	
Calidris fuscicollis	White-rumped Sandpiper	
Calidris maritima	Purple Sandpiper	
Calidris minutilla	Least Sandpiper	
Calidris pusilla	Semipalmated Sandpiper	Species of Special Concern
Cardellina pusilla	Wilson's Warbler	
Cardinalis cardinalis	Northern Cardinal	
Cathartes aura	Turkey Vulture	
Catharus ustulatus	Swainson's Thrush	
Chaetura pelagica	Chimney Swift	Species of Special Concern
Charadrius semipalmatus	Semipalmated Plover	
Charadrius vociferus	Killdeer	
Chroicocephalus philadelphia	Bonaparte's Gull	Species of Special Concern
Circus cyaneus	Northern Harrier	Species of Special Concern
Cistothorus palustris	Marsh Wren	
Colaptes auratus	Northern Flicker	
Columba livia	Rock Pigeon	
Corvus brachyrhynchos	American Crow	

(continued)

TABLE 2 *(Continued)*

Scientific Name	Common Name	State Listing
Corvus ossifragus	Fish Crow	
Cyanocitta cristata	Blue Jay	
Dendroica caerulescens	Black-throated Blue Warbler	
Dendroica pensylvanica	Chestnut-sided Warbler	Species of Special Concern
Dendroica striata	Blackpoll Warbler	
Dendroica virens	Black-throated Green Warbler	
Dolichonyx oryzivorus	Bobolink	
Dryocopus pileatus	Pileated Woodpecker	
Dumetella carolinensis	Gray Catbird	
Egretta caerulea	Little Blue Heron	
Egretta thula	Snowy Egret	
Empidonax alnorum	Alder Flycatcher	
Empidonax traillii	Willow Flycatcher	
Empidonax virescens	Acadian Flycatcher	
Falco peregrinus	Peregrine Falcon	Endangered
Gallinago delicata	Wilson's Snipe	
Gavia immer	Common Loon	
Geothlypis trichas	Common Yellowthroat	
Haemorhous mexicanus	House Finch	
Haemorhous purpureus	Purple Finch	
Haliaeetus leucocephalus	Bald Eagle	Species of Special Concern
Hirundo rustica	Barn Swallow	Species of Special Concern
Hylocichla mustelina	Wood Thrush	Species of Special Concern
Icterus galbula	Baltimore Oriole	
Icterus spurius	Orchard Oriole	Species of Special Concern
Larus argentatus	Herring Gull	
Larus delawarensis	Ring-billed Gull	
Larus marinus	Great Black-backed Gull	
Limnodromus griseus	Short-billed Dowitcher	
Megaceryle alcyon	Belted Kingfisher	
Melanerpes carolinus	Red-bellied Woodpecker	
Melanitta fusca	White-winged Scoter	
Meleagris gallopavo	Wild Turkey	
Melospiza georgiana	Swamp Sparrow	
Melospiza melodia	Song Sparrow	
Mergus merganser	Common Merganser	
Mimus polyglottos	Northern Mockingbird	

Scientific Name	Common Name	State Listing
Mniotilta varia	Black-and-white Warbler	Species of Special Concern
Molothrus ater	Brown-headed Cowbird	
Myiarchus crinitus	Great Crested Flycatcher	
Nycticorax nycticorax	Black-crowned Night Heron	Threatened
Oreothlypis ruficapilla	Nashville Warbler	
Pandion haliaetus	Osprey	
Parkesia noveboracensis	Northern Waterthrush	
Passer domesticus	House Sparrow	
Passerculus sandwichensis	Savannah Sparrow	
Phalacrocorax auritus	Double-crested Cormorant	
Pheucticus ludovicianus	Rose-breasted Grosbeak	
Picoides pubescens	Downy Woodpecker	
Picoides villosus	Hairy woodpecker	
Plegadis falcinellus	Glossy Ibis	
Pluvialis squatarola	Black-bellied Plover	
Poecile atricapillus	Black-capped Chickadee	
Porzana carolina	Sora	
Quiscalus quiscula	Common Grackle	
Rallus limicola	Virginia Rail	
Rallus longirostris	Clapper Rail	
Regulus calendula	Ruby-crowned Kinglet	
Regulus satrapa	Golden-crowned Kinglet	
Riparia riparia	Bank Swallow	
Sayornis phoebe	Eastern Phoebe	
Seiurus aurocapilla	Ovenbird	
Setophaga coronata	Yellow-rumped Warbler	
Setophaga magnolia	Magnolia Warbler	
Setophaga petechia	Yellow Warbler	
Setophaga pinus	Pine Warbler	
Setophaga ruticilla	American Redstart	Species of Special Concern
Sialia sialis	Eastern Bluebird	
Sitta canadensis	Red-breasted Nuthatch	
Sitta carolinensis	White-breasted Nuthatch	
Somateria mollissima	Common Eider	
Sphyrapicus varius	Yellow-bellied Sapsucker	
Spinus tristis	American Goldfinch	
Spizella passerina	Chipping Sparrow	

(continued)

TABLE 2 *(Continued)*

Scientific Name	Common Name	State Listing
Stelgidopteryx serripennis	Northern Rough-winged Swallow	Species of Special Concern
Sterna hirundo	Common Tern	Species of Special Concern
Sternula antillarum	Least Tern	Endangered
Sturnus vulgaris	European Starling	
Tachycineta bicolor	Tree Swallow	Species of Special Concern
Thryothorus ludovicianus	Carolina Wren	
Toxostoma rufum	Brown Thrasher	Species of Special Concern
Tringa flavipes	Lesser Yellowlegs	Species of Special Concern
Tringa melanoleuca	Greater Yellowlegs	
Tringa semipalmata	Willet	
Tringa solitaria	Solitary Sandpiper	
Troglodytes aedon	House Wren	
Turdus migratorius	American Robin	
Tyrannus tyrannus	Eastern Kingbird	Species of Special Concern
Vireo gilvus	Warbling Vireo	
Vireo olivaceus	Red-eyed Vireo	
Vireo solitarius	Blue-headed Vireo	
Zenaida macroura	Mourning Dove	
Zonotrichia albicollis	White-throated Sparrow	
Zonotrichia leucophrys	White-crowned Sparrow	

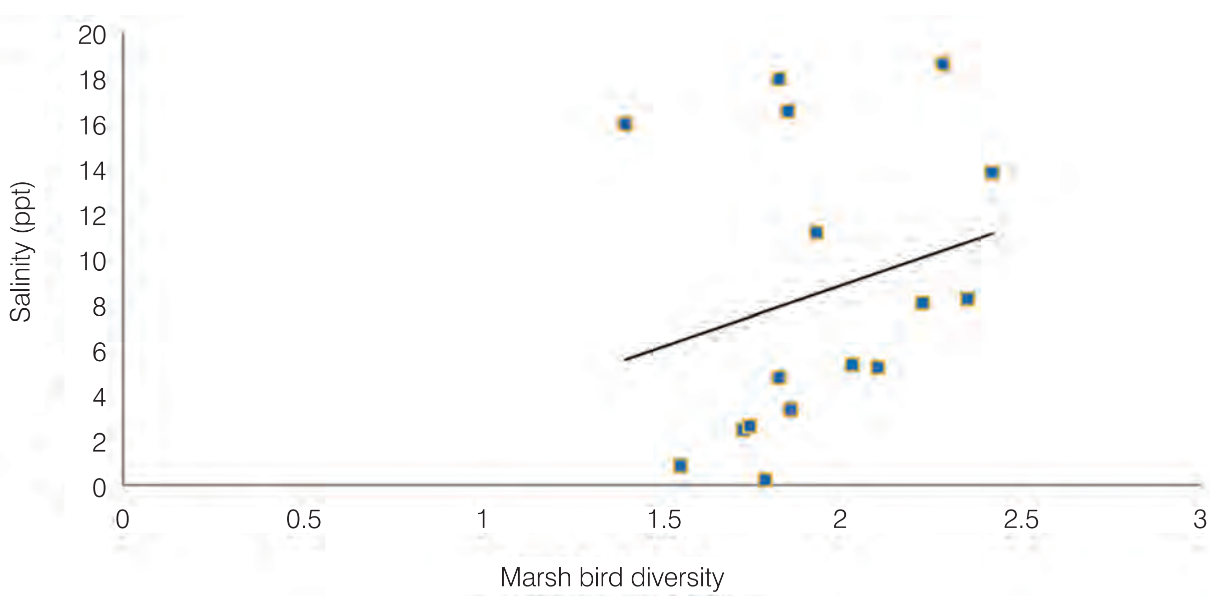

FIGURE 3 Marsh bird diversity was positively associated with increasing salinity in the Saco River.

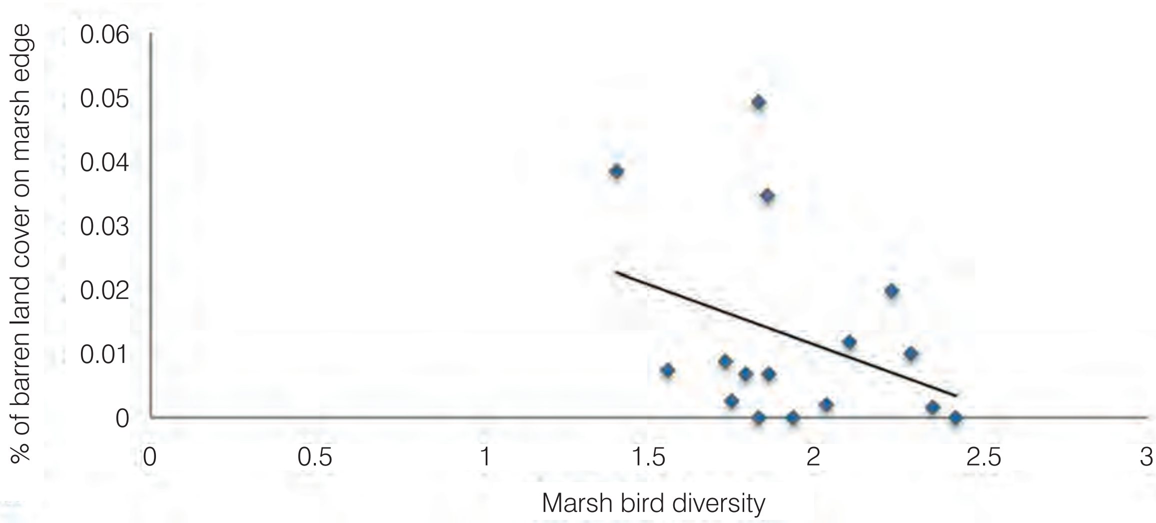

FIGURE 4 Marsh bird diversity was negatively associated with the percent of barren land on the surrounding edges. Barren land is defined as 15% vegetative coverage, primarily shrubs and no mature tree species.

TABLE 3 Models including the additive or interactive effects of salinity and barren land explained 26% of the variation (Δ_i) in marsh bird diversity. Models with $\Delta_I < 2$ were considered to have substantial support in explaining variation in the data; only models with $\Delta_I < 5$ are shown.

Model	AIC_C	Δ	Δ
Salinity + Barren	6.35	0.00	0.18
Salinity*Open Water (fresh)	7.42	1.07	0.11
Salinity*Barren	8.02	1.66	0.08
Vegetated (Not Forest)	9.02	2.67	0.05
Null (no variables)	9.13	2.77	0.04
Marsh Area + Vegetated (Not Forest)	9.76	3.41	0.03
Barren	10.08	3.72	0.03
Salinity*Vegetated (Not Forest)	10.49	4.14	0.02
Plants*Vegetated (Not Forest)	10.50	4.15	0.02
Open Water (Fresh)	10.53	4.18	0.02
Developed	10.64	4.29	0.02
Forest	10.65	4.30	0.02
Marsh Area*Open Water (Fresh)	10.81	4.46	0.02
Mudflat	10.85	4.50	0.02
Distance to Mouth	11.12	4.76	0.02
Salinity	11.24	4.88	0.02

These small marshes provided critical foraging habitat for a diverse suite of species. Many of the birds counted in the marsh during the breeding season use other types of habitats for breeding, but traveled to these marshes to forage (Table 3). Nonetheless, the marshes do provide breeding habitat for both common and species of conservation concern. For example, Nelson's sharp-tailed sparrow, a species listed as of Special Concern by the State of Maine, bred in three and was counted in four of the 16 marshes. This is notable because these marshes were all substantially smaller than the published home range size of an individual pair (Shriver et al. 2010), suggesting these marshes may be high quality, particularly for habitat-limited species. Because the foraging behavior of marsh birds varies dramatically between species—from birds that hunt insects in the air, such as the tree swallow, to those that probe for insects in the mud and shallow water, such as the Virginia rail—the factors that may make these marshes high quality are diverse. Nonetheless, the marshes likely offer a rich variety of food types, as evidenced by the diversity of birds (see Chapter 6). Finally, Shriver et al. (2004) found that species richness of salt marsh birds in the Gulf of Maine was particularly sensitive to human-developed landscapes surrounding marshes. Human development of land varied across the study sites. However, our results, although at notably smaller scale, indicate that human development of land likely does not have a major influence on marsh bird diversity in the Saco estuary.

FIGURE 5 Birding in the marsh, early morning.

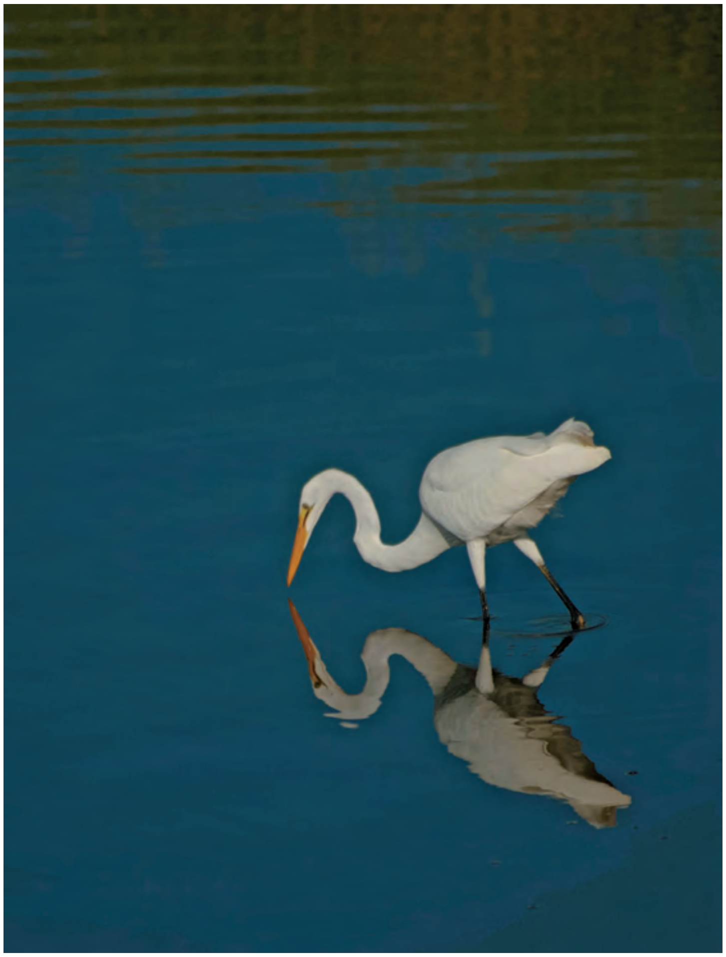

FIGURE 6 Great egret.

CONCLUSIONS

We made the following conclusions from our study of the bird community in the Saco estuary's tidal marshes:

- The total number of bird species observed was 133, representing 40.2% of all species known to occur in Maine.
- A total of 20 of these birds are listed as species of special concern, 1 as threatened, and 3 as endangered in the State of Maine.
- Nelson's sharp-tailed sparrow, a species listed as of special concern by the State of Maine, uses the marshes for breeding and foraging.
- Salinity was the most important factor influencing variation in marsh bird diversity in the tidal marshes of the Saco River.
- Marsh size, extent of invasion by *Phragmites australis*, and shoreline development were not important factors influencing marsh bird diversity.

ACKNOWLEDGEMENTS

Undergraduate students: Will Almeida, Danielle Behn, Chloe Crettien, Sarah Cowles, Chris Dracoules, Cory French, Gale Loescher, Shane Murphy. Thanks also to Biddeford and Saco landowners who allowed us access to the marshes across their property.

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CHAPTER 7

FOOD WEB OF THE SACO ESTUARY'S TIDAL MARSHES

BY CARRIE BYRON

INTRODUCTION

For sustainable management of an ecosystem or resources within an ecosystem, it is not enough to study specific species of interest. It is much more informative for management and conservation decision-making to consider the connections among species in the ecosystem. Connections among most species in an ecosystem can be represented by a food web that provides visual representation of the flow of energy in a system described by predators and their prey. Primary producers (i.e., plants) capture energy from the sun, and then the energy is transferred to animals through herbivory and predation.

Beyond simply mapping predator-prey relationships, a food web characterizes the relative importance of each prey item in a predator's diet. Trophic level details can also be relayed via food web analysis that examines the direction of flow of energy. Bottom-up dynamics describe the flow of energy from primary producers to top order consumers and are dictated by production and food supply. Top-down dynamics describe the effects of consumption on prey populations. For example, predators may control the abundance of their prey (top-down), rather than the prey's food controlling their abundance (bottom-up). All of these relationships and energy flows can be quantified and described mathematically using a model.

Understanding these dynamics is important for the sustainable management of natural resources. People who live, work, and recreate in the Saco estuary value the health of the ecosystem, its ability to support clean water, healthy fish populations for recreational fishing, and natural resources for economic opportunities. People also value wildlife habitat and conservation of natural resources to protect biodiversity. Food web analysis helps to characterize the current state of the ecosystem so that resource managers and policy makers can better understand the dynamics in the system and potentially identify species groups and interactions on which to focus attention.

STUDY OBJECTIVES—FOOD WEB

Our objectives for the food web study were to answer these questions related to the tidal marshes of the Saco estuary:

1. How do species impact each other in the ecosystem?
2. How much do different species overlap with each other in their roles in the ecosystem?
3. How productive is the ecosystem?
4. How resilient is the ecosystem?

RESEARCH DESIGN AND METHODS

A food web for Saco River tidal marshes

The Saco estuary food web model was created specifically to describe the marsh ecosystem. Therefore, species that are restricted to the mid-channel, such as sturgeon, are not included in this model. Also, this model was intended to capture the average summer condition of the ecosystem. The static model presented here is not designed to describe extreme events or perturbations such as storm events. This food web model is limited in that it does not include rare species or species of low biomass. The primary purpose of using this modeling approach is to characterize the overall ecosystem and visualize key predator-prey interactions.

How is a food web model built?

Food web modeling is a simplified method designed to capture the complexity in species interactions. The modeler defines *species groups* based on observations and data collected that describe the organization of the ecosystem. The number of species groups in the model greatly adds to the level of complexity. The inclusion of too many species groups in the model can make the model too cumbersome to explain ecosystem dynamics.

To create a food web model, several parameters need to be measured, including an estimate of a *quantity*, a *rate*, and an *exchange* for every species in the food web. Biomass describes the quantity of species measured as a mass per unit area in the ecosystem. Vital rates describe physiological processes necessary to maintain life, such as metabolism, respiration, and consumption. Diet composition describes the exchange of energy through predation. Biomass (g/m^2 live weight) values for species in the Saco estuary's marsh ecosystem were collected by researchers, and their observations are presented in the relevant chapters of this report.

The parameterization of the model is based on two master equations (www.ecopath.org). The first equation describes how the production term for each species group can be divided (EQ 1). The second equation is based on the principle of conservation of matter within a group (EQ 2, Figure 1).

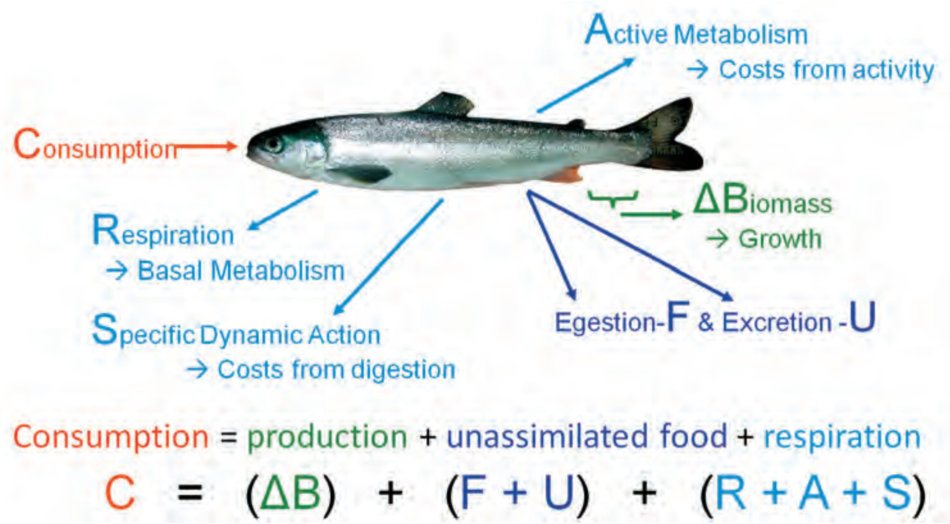

FIGURE 1 Energy balance. *Modified from Kitchell.*

EQ 1: Production = catches + predation mortality + biomass accumulation + net migration + other mortality.

EQ 2: Consumption = production + unassimilated food + respiration.

Vital rates (e.g., production, consumption, and respiration) for fish species were informed by the Fishbase database (www.fishbase.org). Vital rates for birds were informed using an allometric equation presented in peer-reviewed literature (Meire et al. 1994; Scheiffarth and Nehls 1997). Vital rates for many of the Saco estuary invertebrate species were inferred from vital rates presented in other estuarine food webs in peer-reviewed literature (Cusson and Bourget 2005). Diets of all species groups were also informed by online databases and published reports (i.e., Fishbase, Birds of North America, and Cornell Lab of Ornithology).

RESULTS AND DISCUSSION

A food web model for the Saco River's tidal marshes

Food Web Structure

We used 29 species groups in the Saco estuary food web model (Table 1; Figure 2). These species groups are organized by trophic level, with primary producers at the bottom and top consumers at the top of the web. The apex predators of the ecosystem are the colonial water birds, which feed on small fish. American eels are also a top predator in the estuary, feeding on a widely varied diet. Eels were one of the larger fish species found using marsh surface sampling, so eels contribute to a relatively high biomass despite being fewer in number than many other fish species. Like eels, sunfish have a varied diet and have a relatively high trophic status. White suckers occupy a lower trophic level because they feed on benthic invertebrates and lower trophic order species groups. The sunfish also had relatively high biomass due to its large individual size despite relatively lower

TABLE 1 Species functional groups. Saco estuary marsh species with similar ecosystem function (i.e., similar predators and prey) are grouped together in this table.

	Functional Group	Species in Functional Group	Description
1	Rails	*Corvus brachyrhynchos, Rallus longirostris, Gallinago gallinago, Rallus limicola*	Primarily insect-eaters
2	Swallows	*Riparia riparia, Hirundo rustica, Chaetura pelagica, Stelgidopteryx serripennis, Tachycineta bicolor*	Primarily insect-eaters
3	Sparrows	*Ammodramus nelsoni, Agelaius phoeniceus, Melospiza melodia*	Primarily insect-eaters
4	Shorebirds	*Pluvialis squatarola, Tringa melanoleuca, Charadrius vociferous, Calidris minutilla, Tringa flavipes, Calidris maritime, Charadrius semipalmatus, Calidris pusilla, Actitis macularius, Calidris fuscicollis, Tringa semipalmata*	Primarily insect-eaters
5	Colonial Waterbirds	*Megaceryle alcyon, Nycticorax nycticorax, Plegadis falcinellus, Ardea herodias, Ardea alba, Egretta thula*	Primarily fish-eaters
6	Gulls and Terns	*Sterna hirundo, Larus marinus, Larus smithsonianus, Sternula antillarum, Larus delawarensis*	Primarily feed on molluscs and crustaceans
7	Ducks and Geese	*Anas rubripes, Branta canadensis, Anser cygnoides, Anas platyrhynchos, Anas clypeata, Aix sponsa*	Primarily plant-eaters
8	Bluefish	*Pomatomus saltatrix*	Transient species, primarily benthic feeder, mostly juveniles caught
9	Atlantic Silverside	*Menidia menidia*	Transient species, primarily plankton feeder
10	Sticklebacks	*Apeltes quadracus, Gasterosteus aculeatus*	Transient species, primarily plankton feeder
11	White Perch	*Morone americana*	Estuary-dwelling species, primarily plankton feeder
12	Atlantic Herring	*Clupea harengus*	Transient species, primarily plankton feeder

	Functional Group	Species in Functional Group	Description
13	Minnows	*Couesius plumbeus, Notemigonuscry soleucas, Notropis hudsonius*	Freshwater species
14	Yellow Perch	*Perca flavescens*	Freshwater species, primarily benthic feeder
15	Atlantic Tomcod	*Microgadus tomcod*	Estuary-dwelling species, primarily plankton feeder
16	Killifish	*Fundulus diaphanous, F. heteroclites, F. magalis*	Estuary-dwelling species, primarily benthic feeder
17	River Herring	*Alosa pseudoharengus, A. aestivalis*	Diadramous species, primarily plankton feeder
18	Sunfish	*Lepomis macrochirus, L. gibbosus, Micropterus salmoides*	Freshwater species
19	American Eel	*Anguilla rostrata*	Diadramous species, primarily benthic feeder
20	White Sucker	*Catostomus commersonii*	Freshwater species, primarily benthic feeder
21	Sand Shrimp	*Crangon* sp.	Marine crustacean
22	Green Crab	*Carcinus maenas*	Marine crustacean
23	Annelids	*Annelida* sp.	Mud-dwelling segmented worms
24	Molluscs	*Mollusca* sp.	Marine invertebrates possessing a mantle
25	Arthropods	*Arthropoda* sp.	Crustaceans, insects and other animals with exoskeletons
26	Ichthyoplankton	various	Fish eggs and juvenile planktonic stages
27	Marsh Plants	*Spartina* sp., others	Grasses, sedges, succulents
28	Phytoplankton	various	Photosynthetic algae
29	Detritus	various	Decaying organic matter

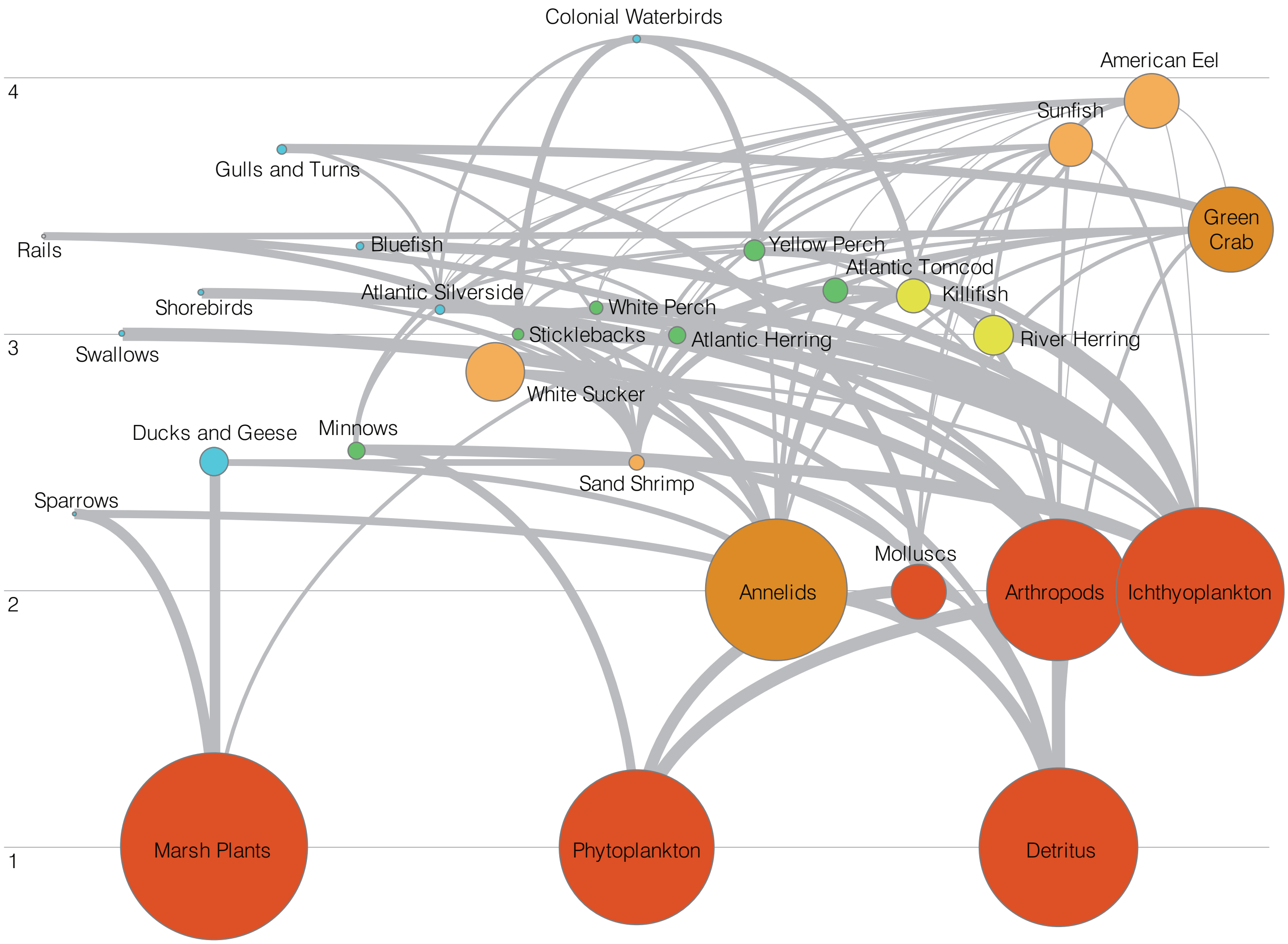

FIGURE 2 Food web diagram for the Saco estuary's tidal marshes. The food web diagram provides several layers of detail of the trophic structure and energy flow within the Saco estuary marsh food web. Circles represent functional groups of species and the size and color of the circle indicate relative biomass. Line thickness describes relative amount of energy flow between species groups. The horizontal number lines represent trophic levels.

abundances in the marshes. It is important to note that a large biomass of small invertebrate species and plankton is needed to support the diverse fish community and bird community. Resource managers interested in maintaining species biodiversity and a stable ecosystem in the Saco estuary should monitor the prey base of plankton and benthic invertebrates because these organisms are essential to the food web.

How species in the food web impact each other

A food web model allows us to understand how each species group impacts other species groups. We can capture these impacts in a mixed trophic impact analysis (Figure 3). This analysis describes the relative impact each predator species has on

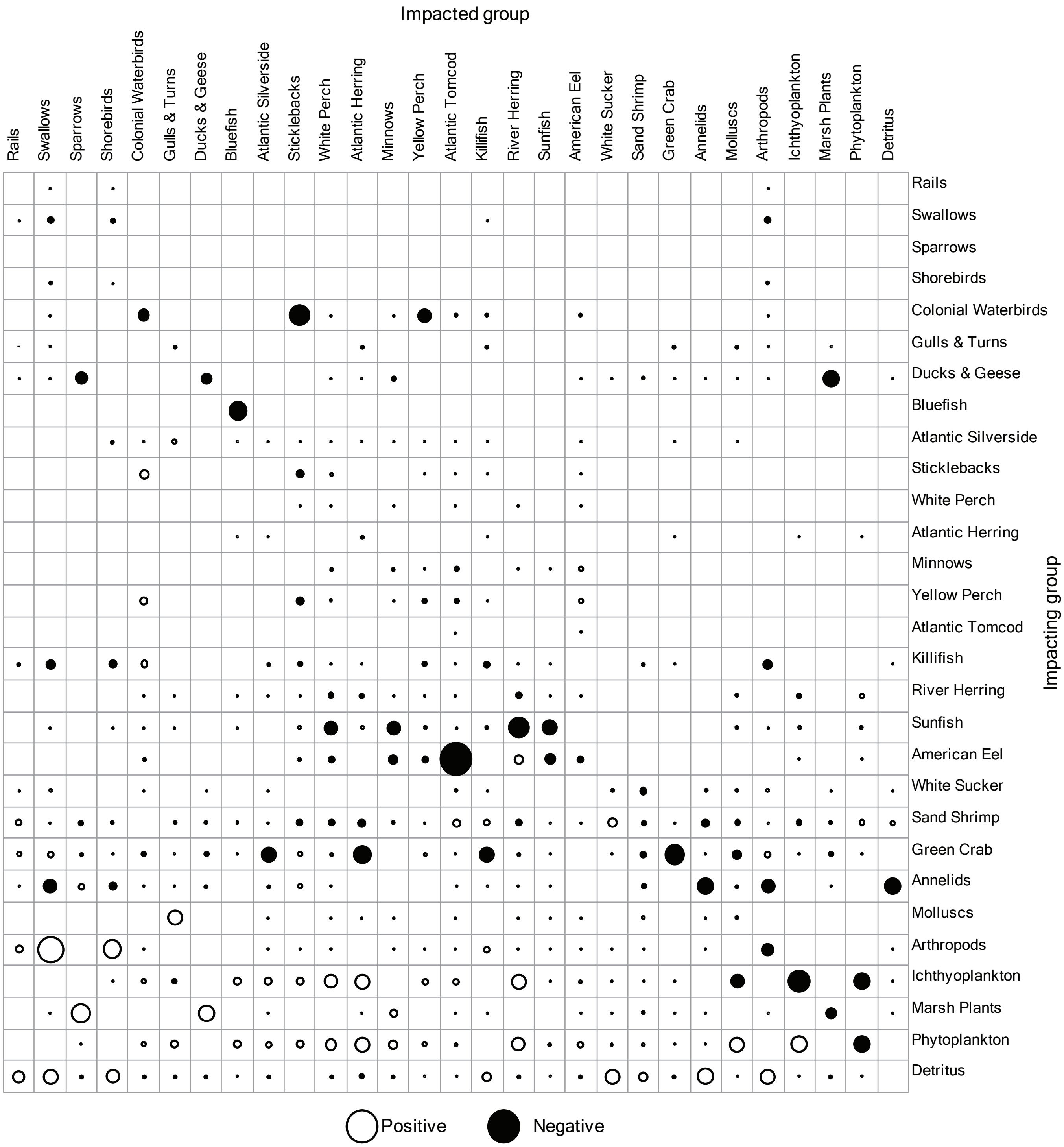

FIGURE 3 Mixed trophic impact analysis. The relative impact each predator species has on each prey species. The figure is designed as a matrix that allows relationship analysis between all species of all trophic levels. Shown along the right are the predators (i.e., impacting species), while prey are shown across the top (i.e., impacted species).

each prey species. The predators (i.e., impacting species) are shown on the right, while the prey (i.e., impacted species) are shown across the top. Impacts may also be caused by competition for prey.

The largest negative impacts in the Saco estuary marsh food web are the American eel on tomcod, sunfish on river herring, and colonial waterbirds on sticklebacks. Almost all species groups have a negative impact on themselves due to intraspecies competition for the same prey.

The largest positive impacts in the estuary's marshes are from arthropods on swallows. Most of the primary producers and first order consumers have a positive impact on most other species because they are the base of the food web supplying energy to higher trophic levels. This flow of energy is indicative of bottom-up processes.

Most of the energy generated by marsh plants and phytoplankton flows up to first and second order consumers. A small portion of it gets used for ecosystem respiration, and much of the rest of it gets recycled as detritus. Detritus, composed primarily of dead and decomposing plants, is an important part of the marsh food web as well. Protecting sediment quality and adequate land area may promote healthy and robust primary production of native rooted plants. Taking action to improve the clarity of water will promote deeper light penetration, thereby stimulating primary production of phytoplankton in the water column.

Niche overlap

Many species depend on the same resources, or prey, as other species. These competing uses are what yield a web-like structure instead of a single chain-like structure when describing the food web. Overlap in resources is described by niche overlap (Figure 4). An ecological niche describes how species utilize resources. The two species with the greatest niche overlap are white perch and river herring, meaning that they share the same prey and the same predators. Other species that have a high degree of niche overlap are: sticklebacks and yellow perch, Atlantic silverside and Atlantic herring, white perch and yellow perch, and sand shrimp and annelids. Conversely, minnows have the lowest degree of niche overlap with killifish, river herring, and white perch.

The concept of niche overlap is a way for managers to assess the organization of species in the food web. High niche overlap can be an indicator of redundancy in energy flow pathways that is necessary for ecosystem stability. On the other hand, species that exhibit low niche overlap may be serving a critical role in maintaining pathways for energy to flow from lower order trophic groups to higher order trophic groups. If these critical species were lost, energy to higher trophic levels also may be lost, thereby decreasing species biodiversity, abundances, and biomasses. The food web model depicted a total of 34 pathways from prey to predators (Figure 1). Maintaining niche overlap will also maintain these energy pathways.

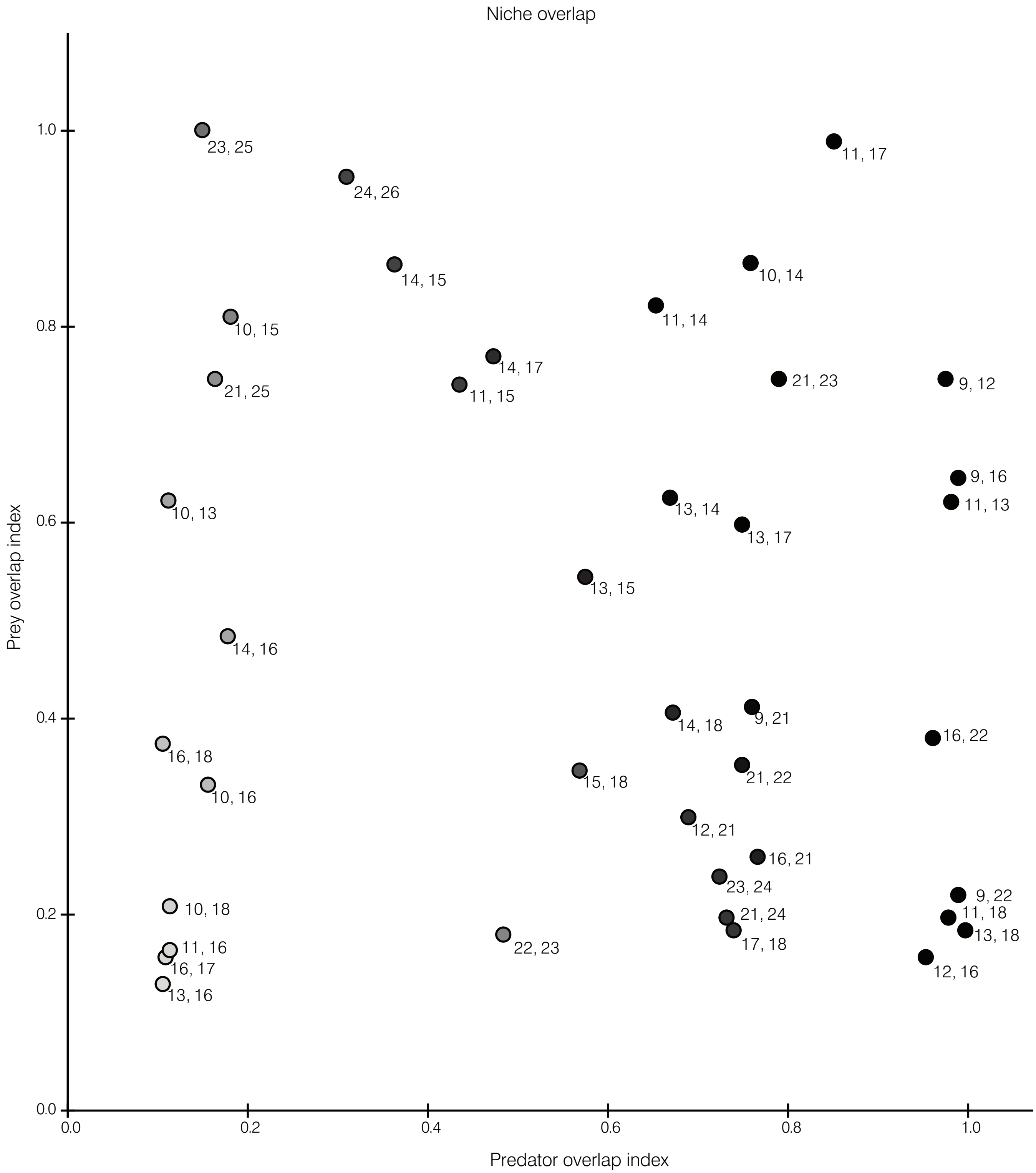

FIGURE 4 Niche overlap between predator and prey. A value of 0 (white dots) suggests that the two species do not share the same resources, and a value of 1 (black dots) indicates complete overlap. Dots in the upper left corner have a high overlap of prey, and dots in the upper right corner have a high overlap of both predators and prey. The numbers next to each dot correspond to particular species groups as presented in Table 1.

Energy: productivity and transfer efficiency

Overall, the Saco estuary is quite productive, with a much higher primary production (PP) rate than respiration (R) rate. High PP/R suggests that the estuary is a highly productive and immature system, which is typical of most marsh systems. High primary production provides much fuel for the system, but it needs to be balanced by the respiration rate of consumers.

The efficiency at which energy is transferred between trophic levels also has implications for the amount of energy that is available to the top consumers. Transfer efficiencies in the estuary's marshes decreased with increasing trophic level as expected and are generally within the typical range of 5-20%.

The health of the Saco estuary's tidal marshes

Ecosystem health—in this case, health of the Saco estuary tidal marshes—can be measured to determine how well the system is functioning. From this information we can assess whether the marsh can maintain its structure and function over time and whether it has the capacity to recover from external stress, such as that from an extreme storm event (Costanza and Mageau 1999). We plotted metrics for these qualities (i.e., degree of organization and resilience capacity) to get a picture of the health of the marsh (see Figure 5). The Saco estuary marsh food web is highly organized and has relatively lower resilience, which is common for young and highly productive systems such as marshes. Much of the energy in young marshes

FIGURE 5 Health of the Saco estuary's marshes. Ecosystem organization and resilience are indicators of health. The Saco estuary's marshes are highly organized, meaning there are a large number and diverse interactions between species. Resilience refers to the ability of the ecosystem to maintain its structure in the presence of stress.

goes to creating additional biomass and developing more complex ecosystem structure. In contrast, the energy in mature marshes goes primarily to maintaining diverse structure, which makes them more resilient (e.g., more likely to withstand storm events without sustaining significant damage to the functioning of the marsh).

CONCLUSIONS

We made the following conclusions from our food web modeling of the Saco estuary:

- Food web modeling is a useful approach to conceptualizing complex dynamics in an ecosystem and can provide valuable information to resource managers looking to develop conservation plans for the Saco estuary.
- There was a lack of data on important prey species (i.e., annelids, arthropods, and molluscs) in the Saco estuary to inform the model for these groups. These prey groups are some of the most critical species groups in the food web for channeling energy from primary producers to higher order consumers. A diverse and robust prey base is essential for the stability of natural resources in an ecosystem.
- From a conservation perspective, it would be advisable to protect the habitat of these prey groups (i.e., sediment) as a precaution until we know more about the role of these species in the Saco estuary.
- A sensitivity analysis revealed six species that were highly sensitive to changes in parameter values in the model: colonial waterbirds (e.g., herons and egrets), sunfish, American eel, white perch, yellow perch, and bluefish. All of these sensitive species are higher order predators. Additional data on the diets of these species could help improve the Saco estuary marsh model.
- Once a food web model is developed, it can be used for asking "what if" type questions. For example, what if the abundance of the invasive green crab (*Carcinus maenas*) in the Saco estuary increases? We manipulated the biomass of green crabs in the food web model to see how an increase in biomass may impact other species groups and the transfer of energy among those groups. At some extreme biomass, competition for resources with other species will cause changes to the structure and function of the Saco estuary marsh ecosystem. Our analyses suggested that the Saco estuary marsh food web could withstand a ten-fold increase in green crab biomass without any change to other species or to the structure or function of the ecosystem. Increases in green crab biomass beyond this carrying capacity limit of the ecosystem will have negative impacts, primarily on annelids and marsh grasses.
- With the aid of a skilled food web ecologist, these types of questions on species impacts or carrying capacity could be addressed for any species of concern in the Saco estuary marsh food web. Such information not only helps to characterize the ecosystem but can also be used to aid resource managers and policy makers in prioritizing research efforts and policy decisions.
- Developing data-intense food-web models helps to highlight areas where more research is needed.

ACKNOWLEDGEMENTS

Data for this food web were informed by field data collected by the labs of James Sulikowski, Noah Perlut, Pam Morgan, Anna Bass, Steve Zeeman and the Wells National Estuarine Research Reserve. Matt Simon helped compile and analyze field data.

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CHAPTER 8

LAND USE AND LAND COVER ALONG THE SACO ESTUARY'S SHORELINE

BY MARK ADAMS

INTRODUCTION

It is important to consider land use and land cover along the river shoreline when trying to determine the health of the Saco estuary, as they influence many characteristics of estuary functioning. The condition of the shoreline adjacent to the tidal marshes is a major factor in determining the use of the marshes for cover or foraging by animals such as deer, birds, and fish. Land cover also potentially influences the distribution and abundance of plant species in the marshes, contributes to the cycling of nutrients and pollutants through the local marsh ecosystem, and influences the amount of freshwater runoff that enters the estuary's marshes and the river itself. Of course, these functions can also be affected by other factors, such as the land use and cover throughout the entire watershed and the ocean currents and tides, but we chose to focus on the lands immediately adjacent to the estuary's edge given their proximity and potential influence on the estuary ecosystem.

Focusing on the shoreline along the river allowed us to develop highly detailed maps of the upland habitats immediately adjacent to the 16 study sites in the tidal marshes in the estuary. We created two sets of maps calculating the types and extents of land cover within roughly 0.25 mile of the center of the estuary channel. The first set of maps depicts land cover in 2009, roughly concurrent with the collection of other biodiversity data in the estuary, which took place in 2010-2013. The second set depicts land cover in 1984 for comparative purposes. To compare the marshes to each other and to other types of field data collected within them, we designated a buffer area extending 100 m beyond the study sites. The findings presented here focus on land cover data from strictly within these buffer areas.

STUDY OBJECTIVES—LAND USE AND LAND COVER

Our objectives for the land use and land cover study were to answer these questions:

1. Can land cover indicators be developed for monitoring the health of the Saco estuary?
2. Were there historical changes in land cover indicators between 1984 and 2009?

RESEARCH DESIGN AND METHODS

Mapping land cover near the Saco Estuary

Because we were interested in studying the possible effects of shoreline development along the Saco River on the estuary's tidal marshes, we chose to make detailed land cover maps of the upland immediately bordering the estuary. We used a set of aerial photographs taken in fall 2009, close to the time when the UNE project team studied the plant and animal species in the tidal marshes.

Our maps of land cover follow the 2006 classification scheme of the National Land Cover Dataset (Figure 1), with a few modifications:

- Barren (#31) is divided into three subclasses: (a) sand, (b) mudflat, and (c) all other barren (mostly rock outcrops). The ecological role of mudflats in the estuary is significant, and we concluded they should be classified separately.
- While we have retained the woody (#90) versus herbaceous (#95) classifications, we only mapped marshes that are tidally influenced, ignoring those in the upland that are not part of the estuary.
- Grassland (#71) is not used for the mown fields in the estuary. Grassland here refers to native, unmaintained grass vegetation; the only examples of such a cover class in the estuary are the small expanses of dune grass behind Hills Beach and Ferry Beach. We chose to classify fields as agriculture-grass (equivalent to #81, pasture/hay), even though it is likely that many such fields are actually not commercial hay harvest operations.

Comparing land cover in 1984 to 2009

We wanted to learn more about the past land cover of the estuary. When researching the availability of historical aerial photographs of the southern Maine coast, we chose to use a set of photographs commissioned by the City of Saco in 1984. The date of the photographs is fairly close to the date of implementation of Maine's mandatory local shoreline zoning ordinance by the City of Saco. Originally passed by the Maine legislature in 1971, this law requires each town in the state to adopt a special category within its land zoning ordinance dealing with the shoreline of rivers,

FIGURE 1 Classification scheme of the National Land Cover Dataset.

ponds, lakes, and the ocean. While towns have some flexibility in determining precisely what land use types are allowed within the special shoreland zone, the law is intended to significantly limit development of new structures within 250 ft of the shoreline. By comparing the 1984 photographs to those from 2009, we can evaluate how much change has occurred within the shoreland zone during nearly the entire duration that the law has been in force in Saco.

When a photograph of the earth's surface is taken from above, only the point on the land surface that is directly perpendicular to the center of the camera lens is rendered in accurate proportion to the elevation above the earth's surface that the plane is flying. Every other point in the photographed scene is proportionally distorted because the earth's surface is curved. Before the points on a map can be accurately located, the distortion must be geometrically corrected through a process known as *orthorectification*. We orthorectified 42 of these 1984 photographs (loaned to the project by the City of Saco) to accurately map the land cover that existed in 1984.

Key land cover indicators for ecosystem health

How can land cover data provide clues to the health of an ecosystem such as the Saco estuary? We highlight three types of land cover information that can contribute to a better understanding of the estuary's health: total developed area, impervious surface area, and characteristics of vegetated, non-developed habitats.

Total developed area

The developed land cover classes encompass all areas of a landscape where people have substantially modified the original vegetation and/or topography. Examples include residential subdivisions, streets, a wastewater treatment plant, a commercial office district, recreational ball fields, and landscaped parks.

To calculate the area of each land cover type, we measured the size and proportion of the area within each marsh where the project team sampled for plant species and associated indicators, plus an additional area extending 100 m outward from the edge of the sampled area (Figure 2). We then calculated the proportion of each land cover type within the 100-m buffer areas, which includes the hatched sampled areas. Areas of open water extending beyond the mudflat were not included.

Which marshes could potentially be most impacted by development? Values in bold in the right-hand column of Table 1 show marshes where developed land covers comprise the majority of the upland land cover.

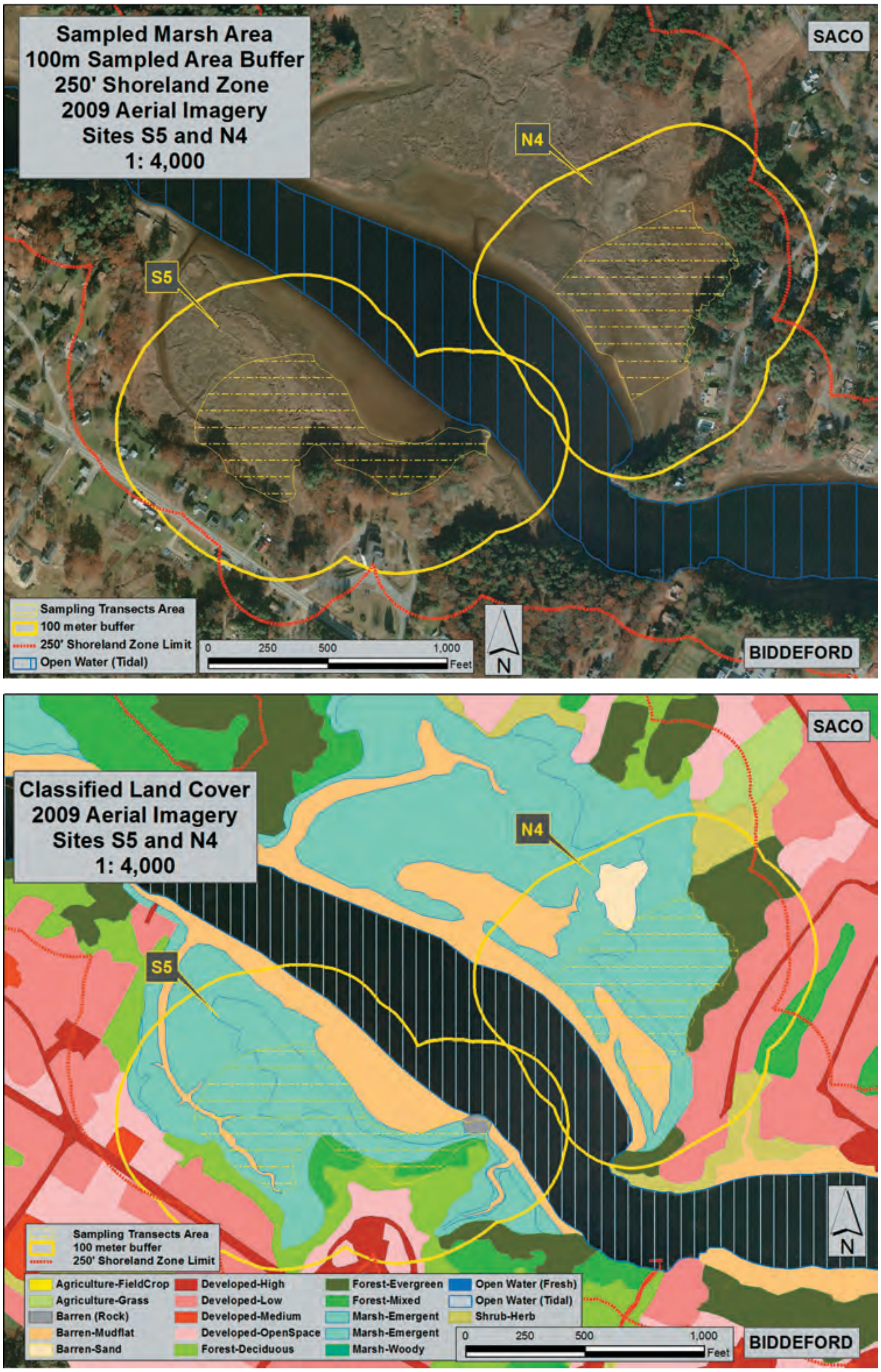
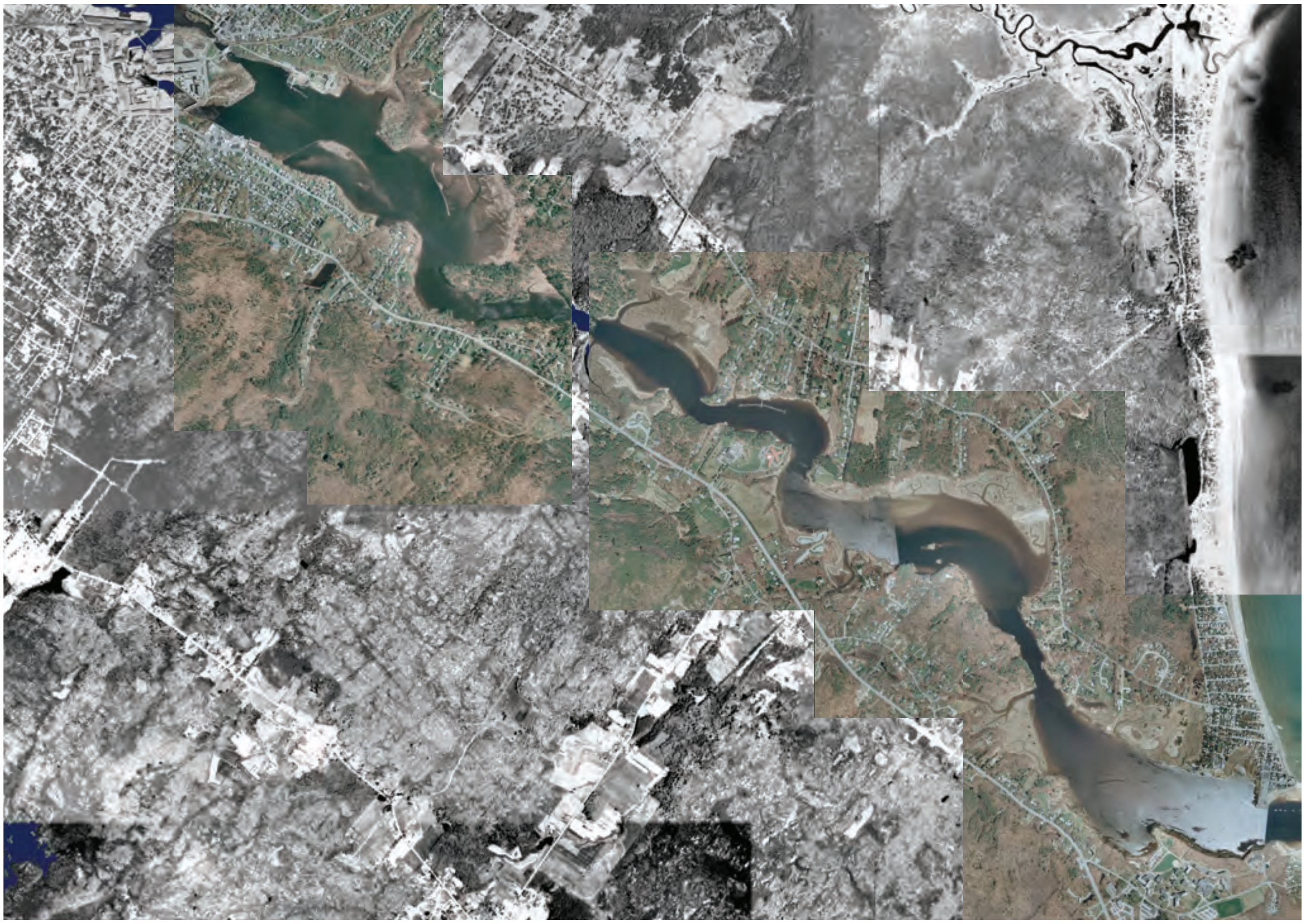


FIGURE 2 100-m buffer around tidal marsh study sites; 2009 land cover classification. The 100-m buffer (heavy yellow line) and tidal marsh sample sites (hatched yellow area) at sites S5 and N4. The lower image illustrates the mapping of land cover areas.

TABLE 1 Total developed area within 100 meters of the sixteen tidal marsh study sites.

Marsh site	Proportion of the area within 100 m of the tidal marsh study site that is developed
N2	18.9%
N3	5.9%
N4	19.2%
N1	**42.0%**
N8	16.5%
N10	**38.4%**
N9	**67.8%**
S1	**38.3%**
S5	19.9%
S4	20.9%
S8	**44.6%**
S6	25.7%
S7	9.2%
S9	9.6%
S10	**40.8%**
S11	25.4%



Impervious surface area

Impervious surface refers to a land surface where water cannot penetrate through, but must run off when rain falls or snow melts. *Developed* land cover includes four classes based on the percentage of impervious surface:

- Open Space: 20% or less of the surface area is impervious. Example: Very large, contiguous domestic lawns lacking any permanent structures.
- Low Intensity: 20-50% of the surface area is impervious. Example: Residential subdivisions on the north side of Ferry Road in Saco.
- Medium Intensity: 50-80% of the surface area is impervious. Examples: Some very large single-family residences with large footprints, associated structures, and driveways are in this class. Other high-density subdivisions, such as at Camp Ellis, are also extensive areas of medium-intensity development.
- High Intensity: 80% or more of the surface area is impervious. Examples: Principal streets and highways. Large institutional buildings and parking lots, such as at UNE and the St. Andre Center in Biddeford.

Table 2 illustrates the finding that at some sites, the majority of "developed" area is actually developed-open space, with little or no impervious surface area. However there *is* a significant amount of high-intensity development in the buffer area at a few sites, such as S10 in Biddeford. At S10, 1.2 ha are at least 80% impervious surface; this area includes buildings and parking lots on the UNE

TABLE 2 Intensity of developed area within 100 m of tidal marsh study sites. This table highlights five marshes, showing the four developed land cover classes defined by relative amounts of impervious surface.

Marsh site	Proportion of the area within 100m of the tidal marsh study site that is developed
N3	5.9%
Open Space	5.2%
Low Intensity	—
Medium Intensity	—
High Intensity	0.8%
N10	38.4%
Open Space	8.3%
Low Intensity	15.5%
Medium Intensity	12.7%
High Intensity	2.2%
S5	19.9%
Open Space	8.0%
Low Intensity	6.9%
Medium Intensity	0.7%
High Intensity	4.3%

Marsh site	Proportion of the area within 100m of the tidal marsh study site that is developed
S7	9.2%
Open Space	0
Low Intensity	4.2%
Medium Intensity	3.5%
High Intensity	1.6%
S10	40.8%
Open Space	24.3%
Low Intensity	0
Medium Intensity	1.6%
High Intensity	14.9%

FIGURE 3 Example of developed area with land cover classifications. These images are of the middle reach of Ferry Road in Saco. The white outlines represent parcel boundaries.

campus immediately adjacent to the tidal marsh. Table 3 presents the 13 marsh sites where the 100-m buffer was composed of roughly 20% or greater total developed area in 2009. The right-hand column shows in which of these marsh buffers development is predominantly (50% or more) impervious surface (developed-medium and developed-high classes).

TABLE 3 Relative intensity of development in marshes with at least ~20% developed area within the 100-m buffer.

Marsh site		Proportion of the area within 100m of the tidal marsh study site that is developed
N2	*Total developed*	18.9%
	> 50% impervious	**14.9%**
N4	*Total developed*	19.2%
	> 50% impervious	**1.7%**
N1	*Total developed*	42.0%
	> 50% impervious	**5.4%**
N8	*Total developed*	16.5%
	> 50% impervious	**5.7%**
N10	*Total developed*	38.0%
	> 50% impervious	**14.6%**
N9	*Total developed*	67.8%
	> 50% impervious	**52.3%**
S1	*Total developed*	38.3%
	> 50% impervious	**26.4%**
S5	*Total developed*	19.9%
	> 50% impervious	**5.0%**
S4	*Total developed*	20.9%
	> 50% impervious	**7.9%**
S8	*Total developed*	44.6%
	> 50% impervious	**22.3%**
S6	*Total developed*	25.7%
	> 50% impervious	**17.8%**
S10	*Total developed*	40.8%
	> 50% impervious	**16.5%**
S11	*Total developed*	25.4%
	> 50% impervious	**15.3%**

The data shown in Table 3 allow researchers to begin to group the 16 marshes of the Saco estuary in terms of the degree to which the ecological systems of each are likely to be negatively impacted by moderately (medium) or very (high) intense development. The ranking of likely impact to ecological communities from adjacent upland development is shown in Table 4. At site N9, adjacent to Camp Ellis pier, more than half of the 100-m buffer is covered by 50% or more impervious

TABLE 4 Summary of likely impact of impervious surfaces in medium- and high-intensity development areas on marsh ecosystems in the Saco estuary.

Marsh Sites	Probability that ecological communities are impacted by development	Total developed area (Table 1)	Total area that is >50% impervious surface (Table 3)	Types of impacts
N9	Very high	> 45%	> 30%	• No upland habitat associated with marsh except for human-adapted foraging species (e.g., gulls) • Large discharges of pollutants from impervious surfaces (most developed area is parking lots and structures)
S11, S10, S6, S8, S1, N2	High	20 – 45%	15 – 30%	• Limited or no upland habitat, except for human-adapted foraging species • Large discharges of pollutants from impervious surfaces (significant developed area is parking lots and structures)
N10	Moderate to High	20 – 45%	15 – 30%	• Limited upland habitat, highly modified (e.g., a single row of trees separating a lawn from the river's edge) • Moderate discharges of pollutants from impervious surfaces • Some nutrient pollution delivered by stormwater runoff from developed but permeable land covers (e.g., lawns)
N4, N1, N8, S5, S4	Moderate	10 – 20%	5 – 15%	• Some upland habitat, but favoring edge species; habitat utilization potentially affected by domestic pets and lawn maintenance • Small discharges of pollutants from impervious surfaces • Some nutrient pollution delivered by stormwater runoff from permeable human-modified land covers (e.g., lawns)
S7, S9	Low	0 – 10%	0 – 5%	• Significant upland habitat with small pockets of developed area • Limited or no pollutant discharge from impervious surfaces • Minimal nutrient pollution delivered by runoff from permeable human-modified land covers
N3	Very low	0 – 10%	0%	• Significant upland habitat (also significant modified habitat preferred by edge species) • No runoff from impervious surfaces • Minimal or no nutrient pollution delivered by runoff

surface. A second group includes sites S11, S10, S6, S8, N2, and S1. For each of these, except for S1, the developed area comprises a combination of a few very large structures and an associated parking lot (i.e., the UNE campus, the Biddeford public boat launch, St. Joseph's Convent, and the Saco wastewater treatment plant, respectively). S1 is adjacent to an inner-Biddeford neighborhood that has been built out for at least a century. A third group, composed of sites N4, N8, N1, S5, and S4, includes marshes adjacent to residential subdivisions where most of the human-modified area is classified as developed-open space or developed-low intensity. Sites S9 and S7, which are not in Table 4, are bordered by just a few residences on large and only partially modified parcels, and the amount of medium- or high-intensity development is limited to the streets that access the properties. Sites N3 and N10 are special cases. For N3, the only adjacent developed area is the lawn of Laurel Hill Cemetery. N10 is the only one of the 16 marshes where significant amounts of land within the buffer are developed for single-family residences, and the residential area also includes significant amounts of medium-intensity area.

Non-developed cover classes

The converse of developed land cover is *natural* land cover, i.e., vegetation that is substantially unmodified by humans. In the Saco estuary in 2009, there were only two types of natural upland land cover: forest and shrub-herb. Mapping the size and extent of non-modified land covers should provide insight into species abundance and diversity at each marsh site. Many species need habitat for foraging or nesting that is as far from an edge as possible. This characteristic can be described using a simple perimeter-to-area (PA) ratio. If the PA ratio is small (e.g., < 0.05), then the shape is compact and its center is roughly equidistant from all the edges of the patch; this is the best configuration for species that need to forage or nest as far from edges as possible. A large PA ratio (e.g., > 0.2) indicates that there is a great deal more perimeter length relative to total area in the patch. The patch is linear in shape, which reduces the distance from an edge to the interior; such patches are less likely to be used by species that need interior habitat. We compared each of the 16 sites for area of forest and shrub habitat as well as for the average of the PA ratios of each patch of forest and shrub within the buffer (Table 5).

Limiting the observations to the 2009 land cover dataset, Table 6 ranks the sites according to their total developed area, intensity of development within developed areas, and extent and configuration of non-modified upland land cover types.

RESULTS AND DISCUSSION

2009 Land Cover Data

Land cover alone does not directly equate to ecosystem health in the estuary system. Rather, the land cover maps and data can guide land managers who may wish to use land use policy tools to favor certain kinds of land covers. The study also provides a baseline dataset on land cover that can assist scientists in further study of the relationships between upland land cover and their observations of plant, bird, invertebrate, and fish species and other ecosystem functions in the Saco estuary. The relative placement of each site's upland land cover characteristics on a scale of 1 to 7 does not necessarily mean that a higher-order site is healthier than a lower-order one. It does mean that the two are highly likely to have very differently functioning ecological systems.

Historical change in key indicators 1984–2009

A potentially powerful explanatory variable for predicting the ecological health of these estuary marshes is a representation of the historical change in the upland cover adjacent to each site. Towns were implementing shoreland zoning ordinances around 1984 to limit development within 250 ft of shorelines as required by Maine state law. For each of the three indicators (i.e., total developed area, relative degree of impervious surface within developed areas, and non-modified habitat types), we examined both the current character of the landscape (derived from interpretation of the 2009 aerial photographs) and the change in landscape character between 1984 and 2009. Table 7 summarizes these findings.

TABLE 5 Forest and shrub land cover types within 100 m of the tidal marsh study sites.

Marsh site	Percent of total area that is forest	Average perimeter-area ratio for all forest areas	Percent of total area that is shrub-herb	Average perimeter-area ratio for all shrub-herb areas
N2	24.5%	0.09	—	—
N3	14.9%	0.09	6.0%	0.11
N4	14.8%	0.08	4.7%	0.09
N1	17.5%	0.10	8.1%	0.14
N8	12.8%	0.11	0.6%	0.17
N10	0.4%	0.19	6.4%	0.12
N9	—	—	—	—
S1	2.2%	0.15	5.8%	0.06
S5	16.9%	0.11	—	—
S4	51.1%	0.09	—	—
S8	21.9%	0.08	—	—
S6	32.2%	0.09	—	—
S7	68.9%	0.06	—	—
S9	24.6%	0.08	—	—
S10	23.9%	0.08	—	—
S11	51.8%	0.04	—	—

TABLE 6 Ranking of Saco Estuary marsh study sites according to proportion of developed area, intensively developed area (i.e., >50% of developed surface is impervious) and non-modified land covers within 100-m buffers.

Rank	Site	Comparative extent of developed area (Table 5)	Relative intensity of development (Table 5)	Comparative extent of non-modified land cover (Table 6)
1	N3	0 – 10%	0	Good to very good (forest); good to very good (shrub)
2	S7	0 – 10%	< 5%	Good to very good (forest); none (shrub)
	S9	0 – 10%	< 5%	Good to very good (forest); none (shrub)
3	N4	10 – 20%	5 – 15%	Good to very good (forest); fair (shrub)
	N8	10 – 20%	5 – 15%	Good to very good (forest); fair (shrub)
	N1	10 – 20%	5 – 15%	Good to very good (forest); fair (shrub)
4	S5	10 – 20%	5 – 15%	Good to very good (forest); none (shrub)
	S4	10 – 20%	5 – 15%	Good to very good (forest); none (shrub)
5	S11	20 – 45%	15 – 30%	Good to very good (forest); none (shrub)
	S6	20 – 45%	15 – 30%	Good to very good (forest); none (shrub)
	N2	20 – 45%	15 – 30%	Good to very good (forest); none (shrub)
6	S8	20 – 45%	15 – 30%	Fair (forest); none (shrub)
	S10	20 – 45%	15 – 30%	Fair (forest); none (shrub)
7	S1	20 – 45%	15 – 30%	Poor to none (forest); fair (shrub)
	N10	20 – 45%	15 – 30%	None (forest); fair (shrub)
8	N9	> 45%	> 30%	None (forest); none (shrub)

TABLE 7 Summary of historical change (1984–2009) in key land cover indicators (developed area, intensely developed area, forest, shrub-herb) adjacent to tidal marshes of the Saco Estuary.

Site	Total Developed Area			Intensely Developed Area			Non-modified Area			
	Extent: 2009 (ha)	% of buffer area: 2009	Change in % 1984–2009	Extent: 2009 (ha)	% of buffer area: 2009	Change in % 1984–2009	Forest: extent, 2009 (ha)	Forest: % of buffer area, 2009	Change in Forest: % of buffer area, 1984–2009	Change in Shrub-Herb: % of buffer area, 1984–2009
N3	1.21	5.9	(NS)	0.15	0.8	(NS)	3.03	14.9	+1.7	– 2.7
S7	0.36	9.2	+ 7.3	0.20	5.1	+ 5.1	2.67	68.9	+10.2	– 14.0
S4	1.30	20.9	(!) – 4.5	0.49	7.9	(NS)	3.18	51.1	+9.3	– 2.5
S9	1.07	9.6	+ 5.8	0.25	2.3	+ 2.7	2.73	24.6	+5.5	– 8.5
N8	2.84	16.5	(!) – 2.6	0.98	5.7	+ 1.3	2.19	12.8	+5.2	– 2.8
N4	2.21	19.2	+ 2.9	0.20	1.7	(NS)	1.66	14.8	-0.7	+ 3.6
S6	2.00	25.7	+ 2.3	1.39	17.8	+3.4	2.51	32.2	+11.4	– 6.8
S11	0.97	25.4	+ 24.8	0.57	15.3	+ 15.3	1.99	51.8	-18.0	– 4.5
N2	1.15	18.9	(NS)	0.90	14.9	+ 9.6	1.49	24.5	+20.6	– 18.1
N1	2.97	42.0	(!) – 6.4	0.39	5.4	(NS)	1.23	17.5	+5.3	+ 3.3
S5	2.72	19.9	(NS)	0.68	5.0	(NS)	2.31	16.9	+5.7	– 2.6
N10	4.60	38.0	+ 11.9	1.75	14.6	+ 10.2	0.04	0.4	-6.7	(NS)
S10	3.47	40.8	(NS)	1.41	16.5	+ 2.1	2.03	23.9	+11.0	– 9.6
S8	2.19	44.6	+ 43.9	1.10	22.3	+ 22.3	1.08	21.9	+8.6	– 14.4
S1	4.29	38.3	+ 5.3	2.97	26.4	+ 2.4	0.25	2.2	(NS)	– 8.6
N9	5.84	67.8	(#) + 5.1	4.50	52.3	+ 7.1	0	—	—	(NS)

(#) The area mapped in the 1984 and 2009 images is not always exactly the same. Differences occur when the area that is *mudflat*, relative to the area of *open water, tidal*, is not the same. The open water portion of each buffer is excluded from the total area that is used for the proportional calculation.

(!) Negative changes may occur in the percent developed area. Developed means human-modified, and not strictly paved over land. If an area of vegetation has been cleared and maintained, then later is unmaintained, woody shrubs or young saplings invade the formerly modified, maintained vegetation. These are classed as non-developed land cover on the 2009 even if the 1984 land cover was developed. The non-utilized Notre Dame Center property adjacent to site S4 illustrates this process well.

Change in developed area 1984-2009

The main conclusion to draw from the data is that, for the most part, there were only modest increases in the total developed area adjacent to the estuary marshes since 1984. The pattern of rural large lot subdivision development along the estuary was mostly already established by 1984. Only at site N10 in Saco did development increase significantly within 100 m of the marsh sampling areas during the time period as a result of residential subdivision development (Figure 4). Single-family home construction did occur around the estuary, but it is typically scattered in isolated parcels rather than concentrated in major subdivision developments. Site S9, where four large single-family homes (one with a very large associated lawn and three with more modest ones) were constructed near the marsh, illustrates this moderate increase in developed area. In addition, most of the additional developed area is modified vegetation (e.g., lawn) rather than pavement or structures.

Change in intensity of development 1984–2009

The buffer areas of only four sites experienced significant increases in moderate to very intense development after 1984. Two of these resulted from major construction projects instigated by institutional expansion. At S8, the construction of St. Joseph's Convent adds roughly 1.1 ha of 100% impervious surface to the buffer area after 1984 (Figure 5). The construction of the East Hall and West Hall dormitories by UNE adds just under 0.6 ha of impervious surface to the buffer area at site S11. The impact of these construction projects may have been different, however. The convent was built on an already developed area, classified as agriculture-grass in 1984. The dormitories and service road replaced part of a compact and fairly extensive stand of deciduous forest.

Change in area of unmodified upland vegetation 1984-2009

The most obvious trend in change in forest cover since 1984 is a general tendency toward greater forest area (Figure 6). The area within the 100-m buffers covered by deciduous, evergreen, and coniferous forests combined in 2009 is 59.3 ha larger than in 1984. Six sites gained 7 ha or more of forest cover within their buffers and/or the area in the buffer that is forest increased by 10%. Almost all the forest cover increase is the result of transition from shrub-herb or open land cover to forest. There are only two sites where forest cover area was significantly reduced after 1984: N10 and S11.

Shrub-herb land cover declined across the 16 sites by nearly 67 ha. Note that the area of shrub-herb lost is greater than the area of forest gained. This implies that some shrub-herb land cover was replaced by development.

FIGURE 4 1984 and 2009 aerial images for marsh N10, Saco. Red arrows identify ten single-family residential structures and associated outbuildings within or adjacent to the 100-m buffer that were constructed after 1984. Note the position of the 250-ft shoreland zone boundary.

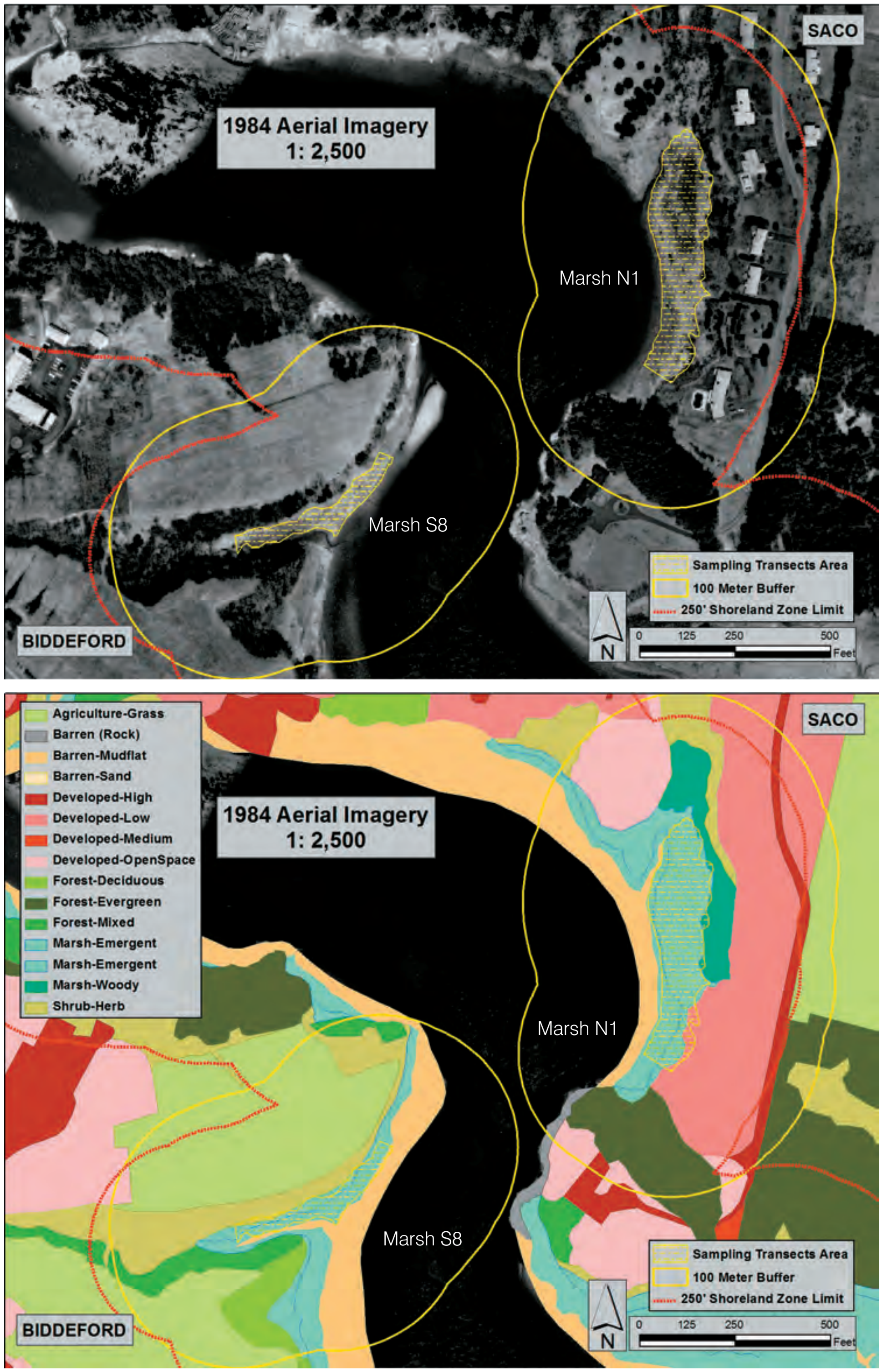
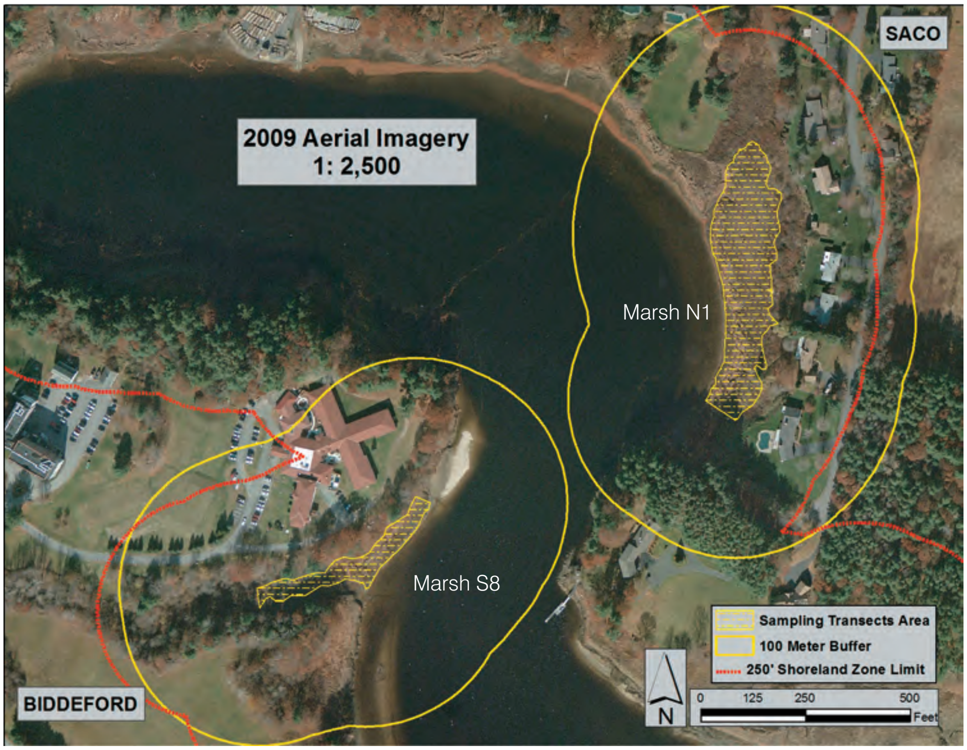


FIGURE 5A 1984 aerial images for marsh N1, Saco and marsh S8, Biddeford.



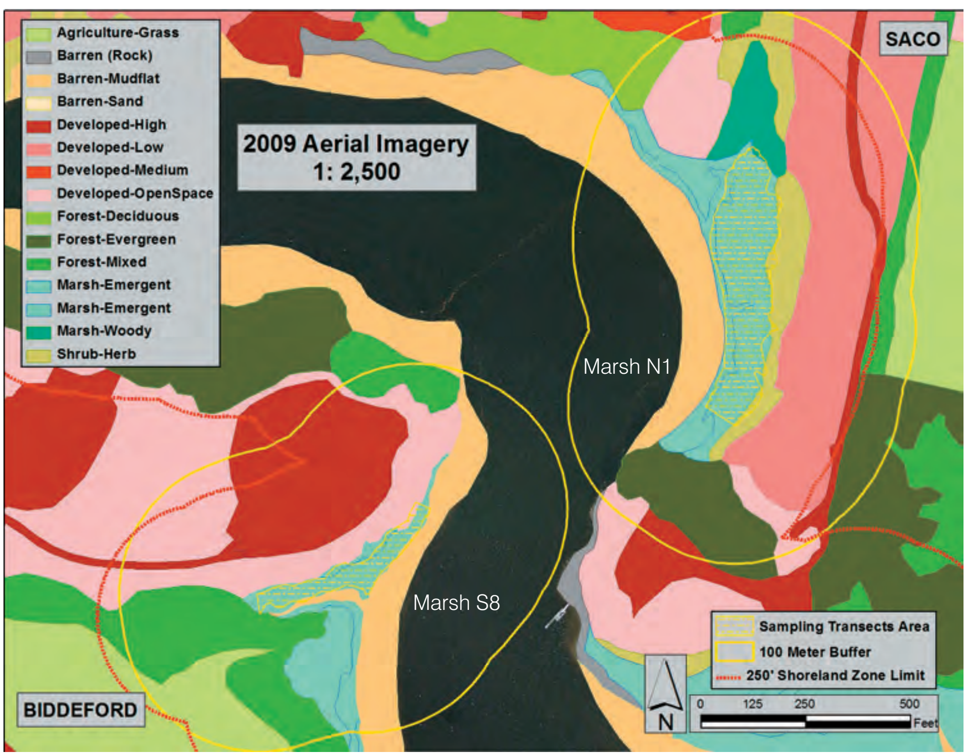


FIGURE 5B 2009 aerial images for marsh N1, Saco and marsh S8, Biddeford.

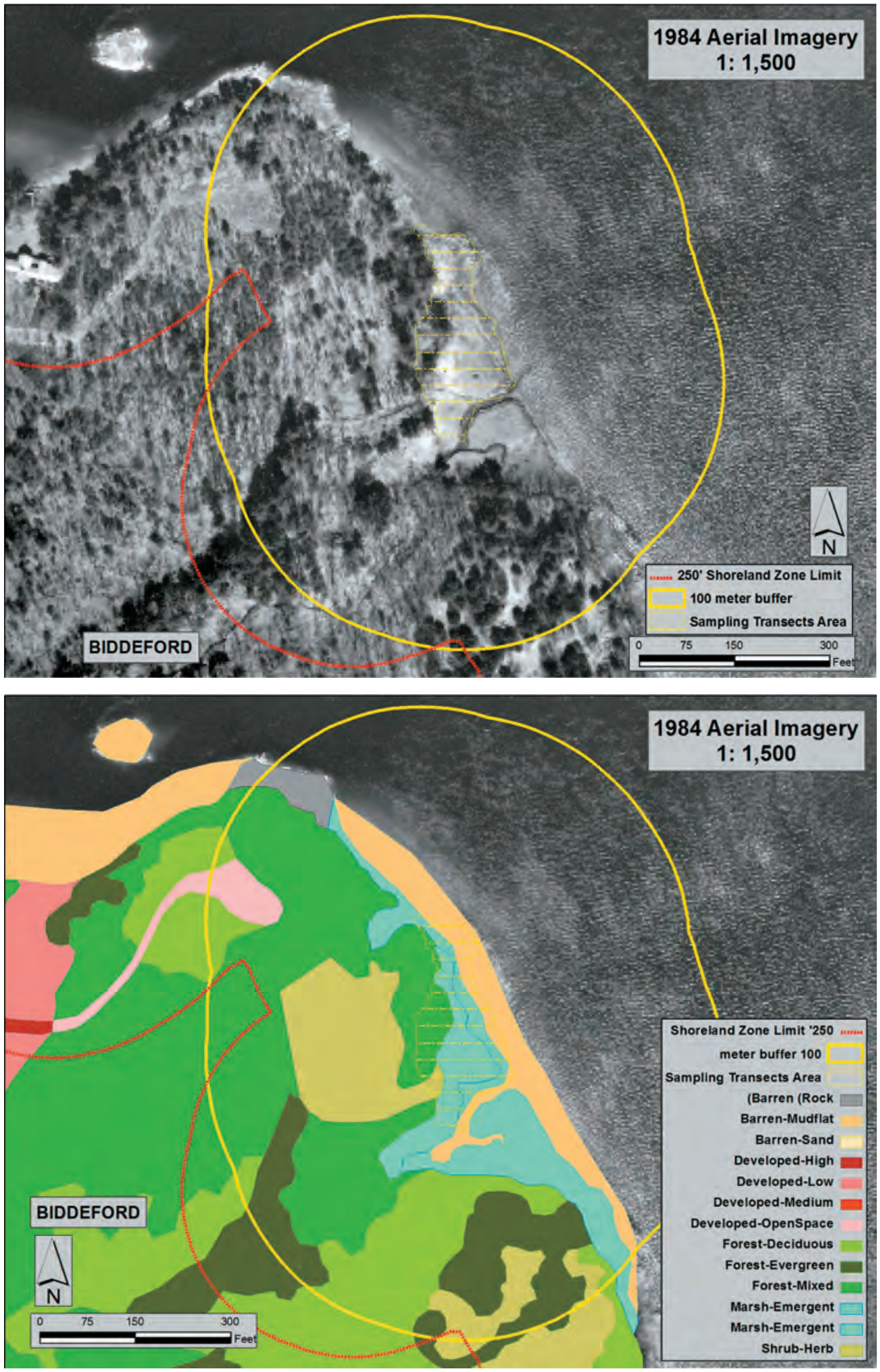


FIGURE 6A 1984 aerial images for marsh S7, Biddeford.

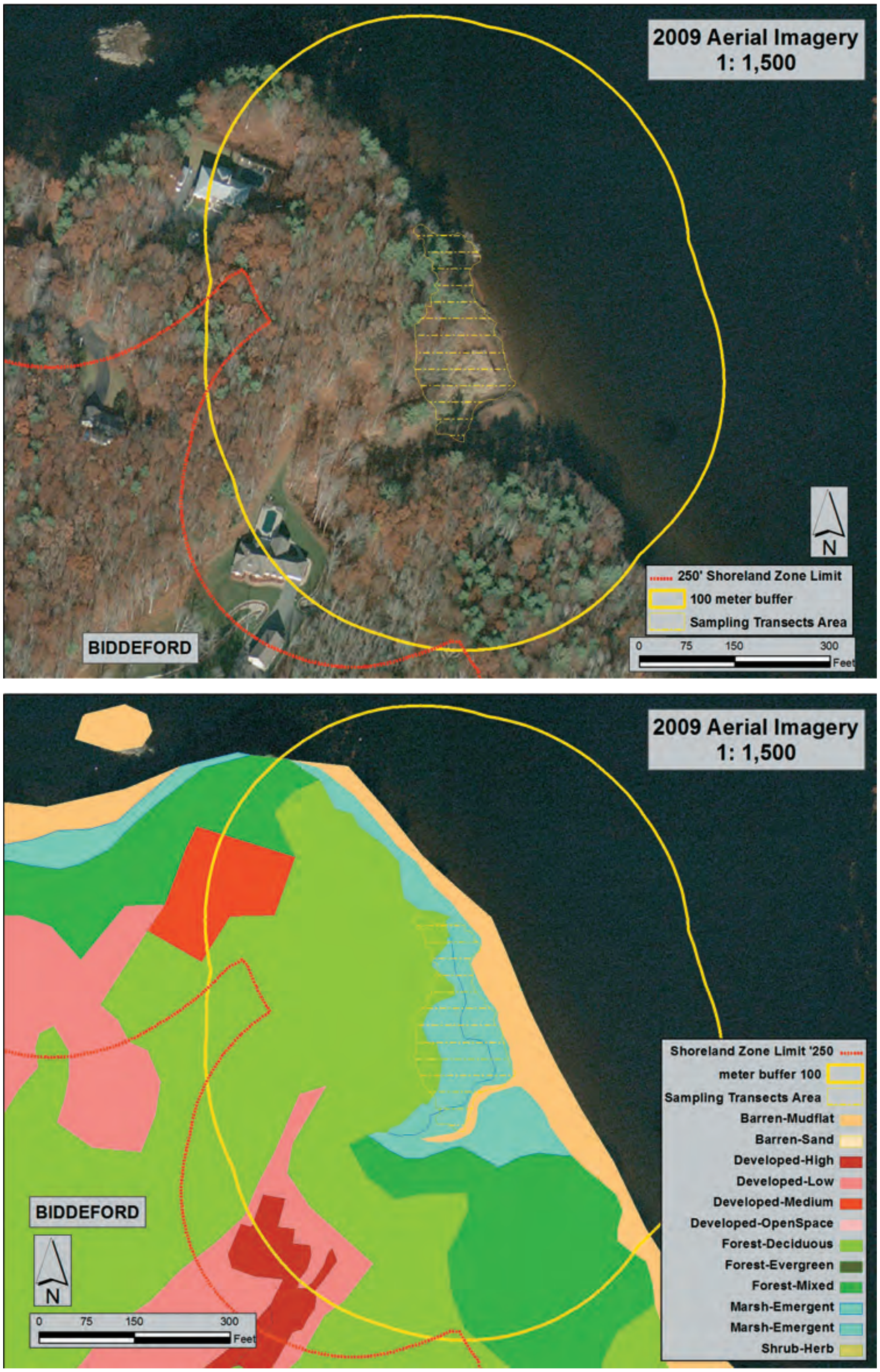
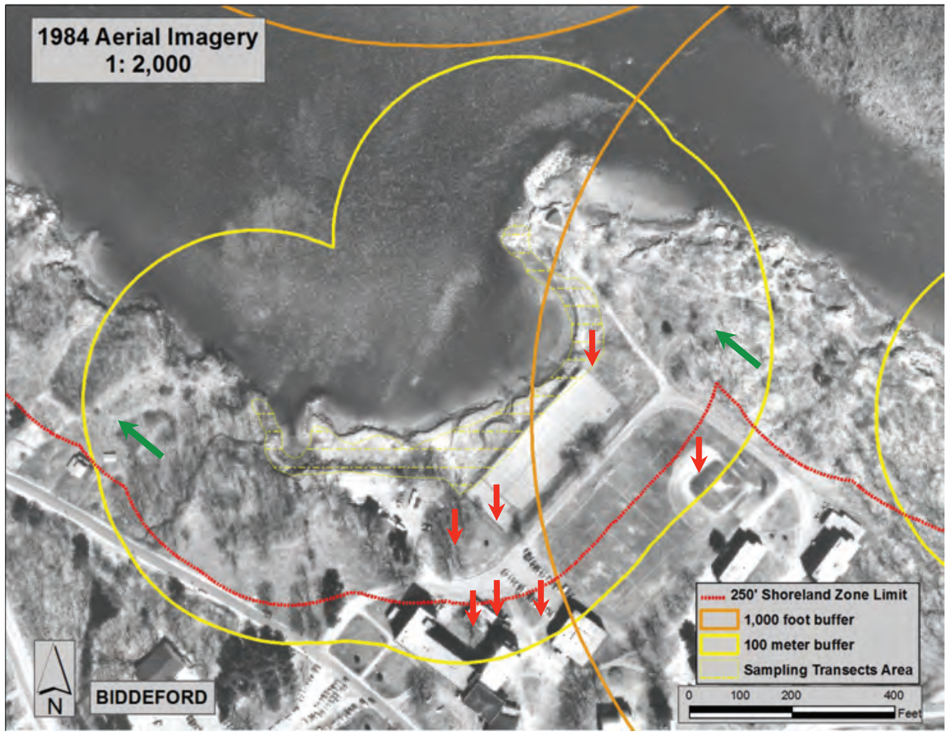


FIGURE 6B 2009 aerial images for marsh S7, Biddeford. All remaining shrub-herb cover in 1984 disappears, replaced by forest cover through an expected successional pathway. Areas of evergreen forest give way to mixed forest (lower right) and to development of a residence (lower center). Mixed forest transitions to all deciduous.



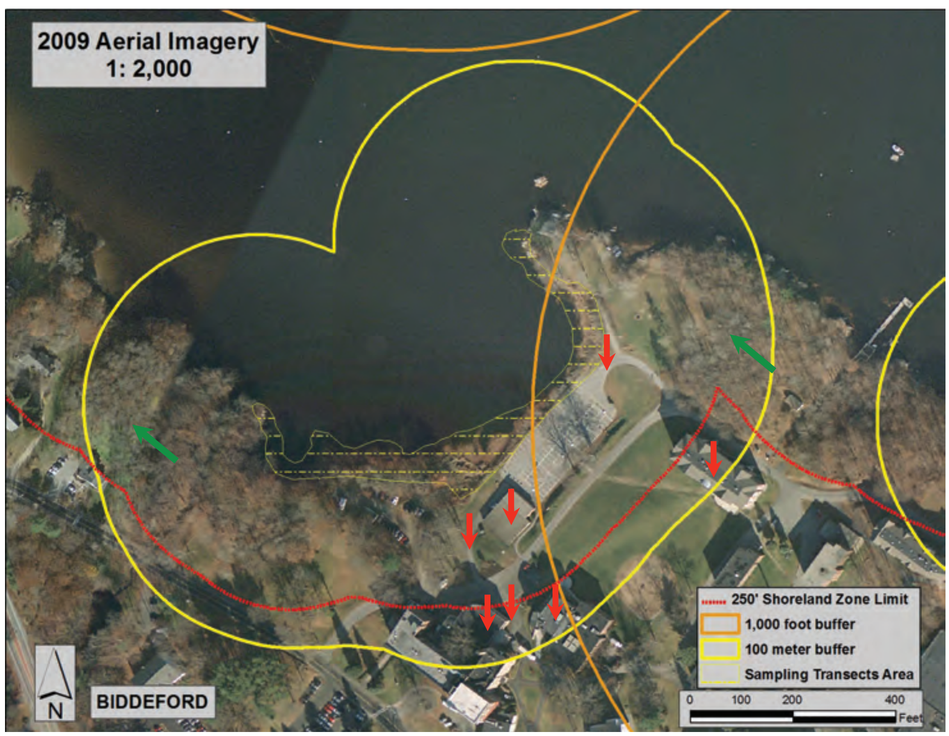


FIGURE 7 1984 and 2009 aerial images for marsh S10, Biddeford. The completion of new structures and roadways (red arrows) on the UNE campus illustrates impacts to the upland borders of a marsh as well as forest succession (green arrows). This is one of the few sites in the estuary where the area of developed-open space actually shrinks during the 25-year interval, as it is replaced with either forest cover or new structures and roadways.

CONCLUSIONS

We made the following conclusions from our study of land cover change data (1984-2009) in the Saco River watershed:

- Major development occurred at three sites after 1984. These are sites where the proportion of the buffer area that is intensely developed increased more than 10%: S11, N10, and S8.
- There was the accumulation of an additional 54 ha of forest area within the 16 buffer areas between 1984 and 2009, and the disappearance of 68 ha of shrub-herb area.
- The overall picture of the estuary that emerges from examining land cover in 2009 and 1984 is one of relative stability.

ACKNOWLEDGEMENTS

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CHAPTER 9

SEA LEVEL RISE AND THE SACO ESTUARY

TIDAL MARSHES

BY MICHAEL ESTY

INTRODUCTION

One of the consequences of climate change is that the seas are rising. Sea level rise will have a significant impact on tidal wetlands worldwide, including the tidal marshes of the Saco Estuary. It will also affect areas that border the tidal marshes. Fortunately, tidal marshes have the ability to accumulate sediments vertically and grow in elevation, so they will not necessarily be drowned out by rising seas. Scientists have discovered that one possible future scenario for tidal marshes is that, as the sea rises, marshes will accrete sediments and move inland. This is called *marsh migration*. But tidal marshes do not always have someplace to go—human or natural barriers to marsh migration can prevent marsh movement and result in marshes decreasing in size (Torio and Chmura 2013). This prevention of marsh movement is known as *coastal squeeze*. Because tidal marshes protect against flood, storm, erosion and wave damage, it may be prudent to plan ahead to mitigate the effects of coastal squeeze on the Saco Estuary's tidal wetlands. In addition, with more frequent storms predicted for the future, understanding how storm surge and flooding events are affected by sea level rise is important to make wise management decisions.

Tidal marshes are complex systems, as shown in all chapters of this report. To model what might happen to them and plan for the future requires involvement of local municipalities. Modeling the effects of sea level rise requires a large amount of data and local review if the models are to be useful in specific locations. Examples of local studies of the impacts of sea level rise on communities are the Town of Cape Elizabeth report (Slovinsky 2013) and the Climate Vulnerability Assessment for Coastal Washington County (Johnson and East 2014).

STUDY OBJECTIVES—SEA LEVEL RISE

Our objectives for the sea level rise (SLR) study were to answer these questions related to the tidal marshes:

1. Based on a model of SLR using the latest light detection and ranging (LiDAR) data, digital elevation models, orthophotos, tidal marsh definitions,

sea level rise data, and other information, how might the tidal marshes of Biddeford and Saco be affected by ongoing sea level rise?

2. What are some potential steps that could be taken to prepare Biddeford and Saco for the increasing effects of SLR?

RESEARCH DESIGN AND METHODS

There are several ways to map a tidal marsh. One can survey the marsh in the field with a Global Positioning System (GPS) and/or map its vegetation and other characteristics. A tidal marsh can also be defined using orthophotos (i.e., aerial photographs that have been corrected or orthorectified). These methods are expensive and time consuming. They also require a great deal of expertise. A third method is to define the tidal marsh as the area between the low tide level and the Highest Annual Tide (HAT). Community zoning tends to use the third definition. There is also some discussion about which high tide level to use, but the HAT level

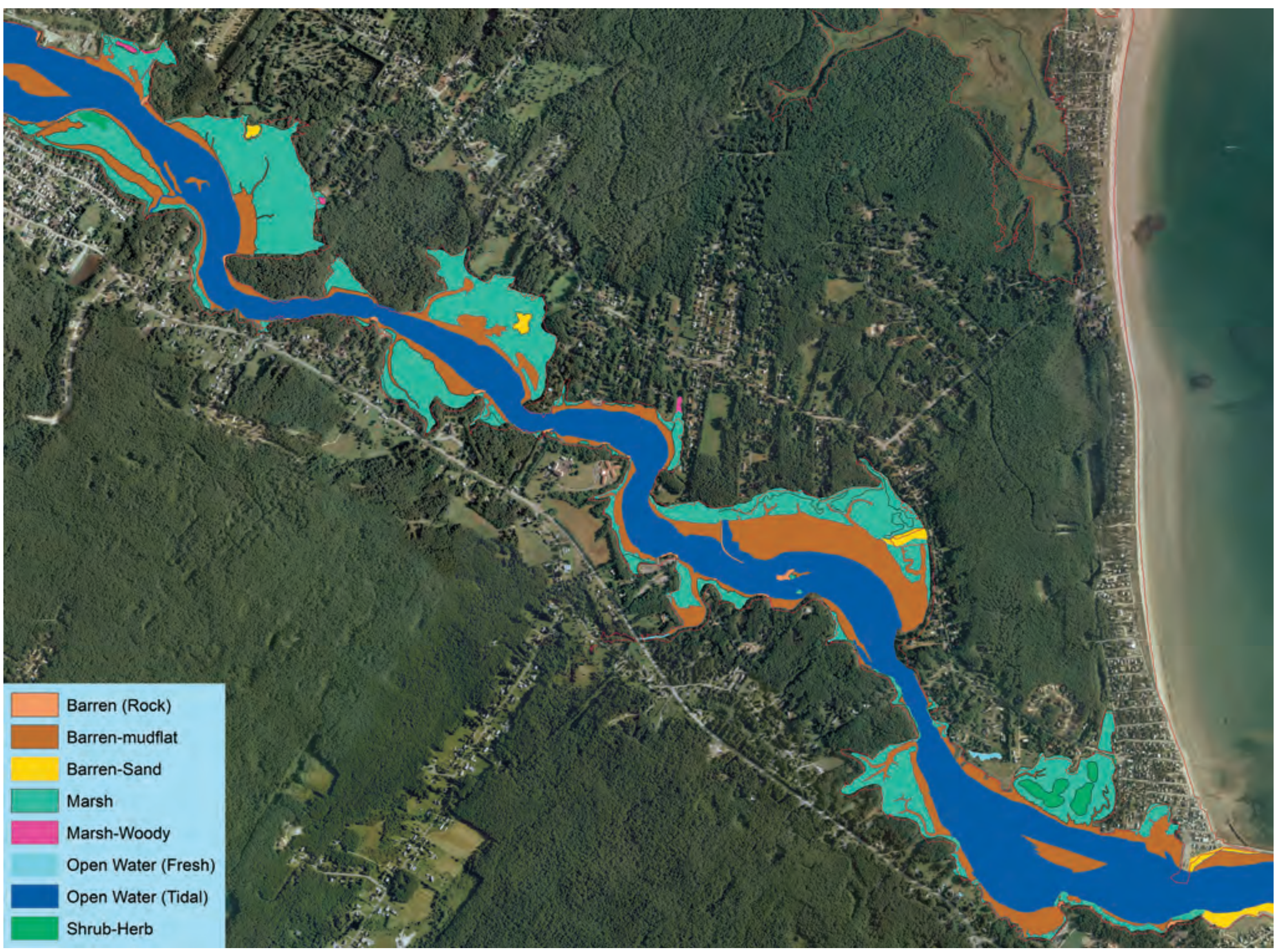

FIGURE 1 Current tidal marshes of the Saco Estuary.

is commonly used in Maine (Slovinsky 2013). Maine's Highest Annual Tide Levels are located at http://www.maine.gov/dep/land/slz/predictions.pdf.

The City of Saco Zoning Ordinance defines a coastal wetland as:

All tidal and subtidal lands; all lands with vegetation present that is tolerant of salt water and occurs primarily in a salt water or estuarine habitat; and any swamp, marsh, bog, beach, flat or other contiguous low land that is subject to tidal action during the highest tide level for the year in which an activity is proposed as identified in tide tables published by the National Ocean Service.

Figure 1 shows the current tidal marshes in the Saco Estuary. The blue shape is the river at low tide and the red line is the HAT line. Although it is not a perfect match, this map shows that the HAT, orthophotos, and vegetation boundaries are similar.

Which sea level rise scenario should we use?

There are several possible scenarios to review for sea level rise. Low and high average SLR scenarios used by states and communities range from 0.6 to 1.1 m (2 to 3.6 ft) by 2100 (Marcy 2014). We used an intermediate value of 3 ft for the Saco Estuary. It should be noted that the work we present here is just a start to our understanding and planning for SLR in the Saco Estuary. Ideally, one would run several different scenarios when developing a plan for a community. Also, storm surge levels, storm frequency and coastal squeeze are important to model. The flooding and erosion that may be a result of sea level rise should also be a part of local community planning.

RESULTS AND DISCUSSION

Based on a model of SLR using the latest light detection and ranging (LiDAR) data, digital elevation models, orthophotos, tidal marsh definitions, sea level rise data, and other information, how might the tidal marshes of Biddeford and Saco be affected by ongoing sea level rise?

Coastal squeeze will affect the Saco Estuary's marshes

As sea level rises in the coming decades, streets, manmade barriers such as seawalls, and natural ledges will block the tidal marsh from migrating inland. Figure 2 shows examples of barriers to marsh migration in the Saco Estuary. Coastal squeeze will be a major issue in the Saco Estuary, given the large number of barriers present. On the Saco side of the estuary, Route 9, the Camp Ellis development, and other developed areas close to the river are areas of concern for coastal squeeze. On the Biddeford side of the estuary, natural rock barriers are more common. Each marsh in the Saco Estuary should be reviewed and any barriers on its borders further defined and mapped.

FIGURE 2 Human-made and natural barriers in the Saco Estuary. Photos by M. Esty.

A 3-ft SLR scenario for the Saco Estuary[1]

The maps and models that follow were created using Digital Elevation Models (DEM) available from Maine Office of GIS (Digital Elevation Model—2m from LiDAR (4/08/2013) http://www.maine.gov/megis/catalog/). The DEM files were downloaded into a Geographic Information System software program (ESRI ArcMap). An ArcMap tool, raster calculator, was used to select elevation levels. The raster files were converted to polygons using GIS conversion tools. The Erase function was used to create polygons of only the future tidal marshes. Additional metadata on the files are located in the reference section of this chapter and at the sources listed. Orthophotos were downloaded from Geolibrary 6in 2012 CIR (http://mapserver.maine.gov/basemap/index.html). The HAT lines were prepared by Mark Adams.

[1] Disclaimer
The maps and files in this chapter were generated as one scenario of tidal marsh migration using elevation models. They should not be used for other purposes. The data and maps do not account for erosion, subsidence, wind driven tides, complex hydrology, or future construction. They are not meant to be used for navigation or in place of official National Weather Service flood warning and watch forecasts. Onsite evaluation of the data is the user's responsibility. Multiple scenarios and additional data from local, state, and federal organizations should be used in management decisions.

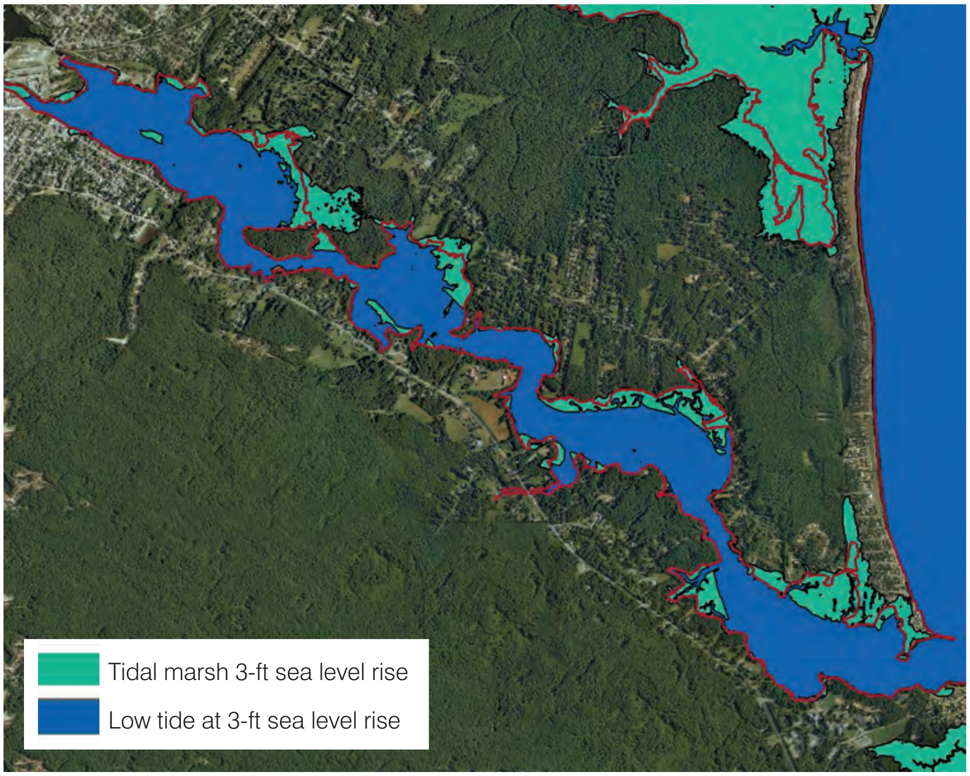

FIGURE 3 Projected 3-ft sea level rise by 2100 in the Saco Estuary. Green areas are predicted future areas of tidal marsh. The blue area is the low tide water level, and the red line is the 2011–2012. Highest Annual Tide (HAT) line.

Figure 3 is a map of the tidal marshes of the Saco Estuary with a projected 3-ft sea level rise in 2100.

The tidal marshes are smaller in this future scenario than they are at the present time. In the Camp Ellis area, the marsh overlaps Route 9 and several houses. Figure 4 shows the marshes overlaid on a current orthophoto. This figure shows many areas of coastal squeeze. Figure 5 shows a marsh in the Cow's Island area that migrates significantly beyond the current HAT line.

Future storm surges will cause more damage because of SLR

Storm surge and flooding are typically also included in SLR modeling scenarios. A 3-ft sea level rise added to the storm surge levels means that significant flooding will be much more frequent in the future. Smaller tidal marshes will provide less of a buffer to these storm surges. Figure 6 is an output map from modeling the flooding during a storm in 1978 plus a 3-ft sea level rise, providing an example of potential future storm surge.

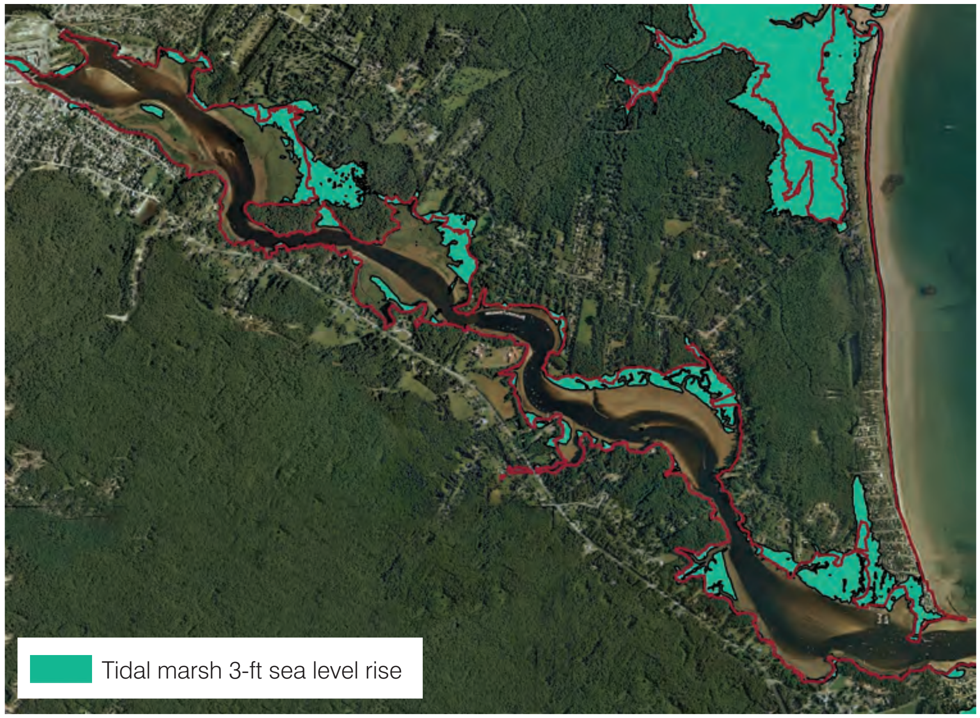

FIGURE 4 Projected 3-ft sea level rise by 2100 scenario showing tidal marshes overlaid on current orthophoto. Note that many of the future tidal marshes are much smaller than marshes existing today. Current HAT line is red.

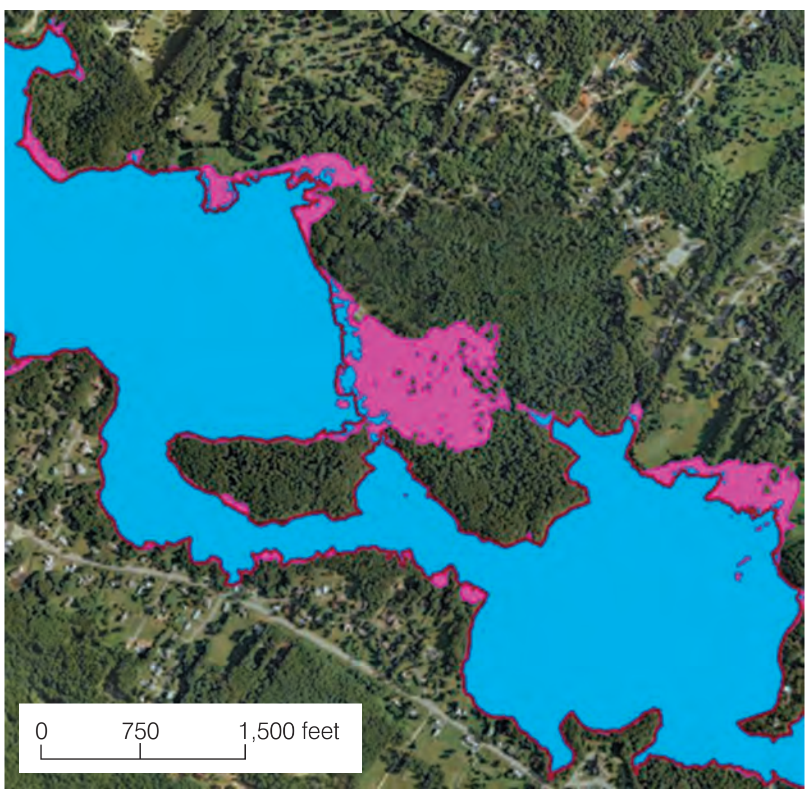

FIGURE 5 Migration of marsh near Cow Island beyond current Highest Annual Tide line in 3-ft sea level rise scenario. Potential (future) marsh is pink, and current HAT line is red.

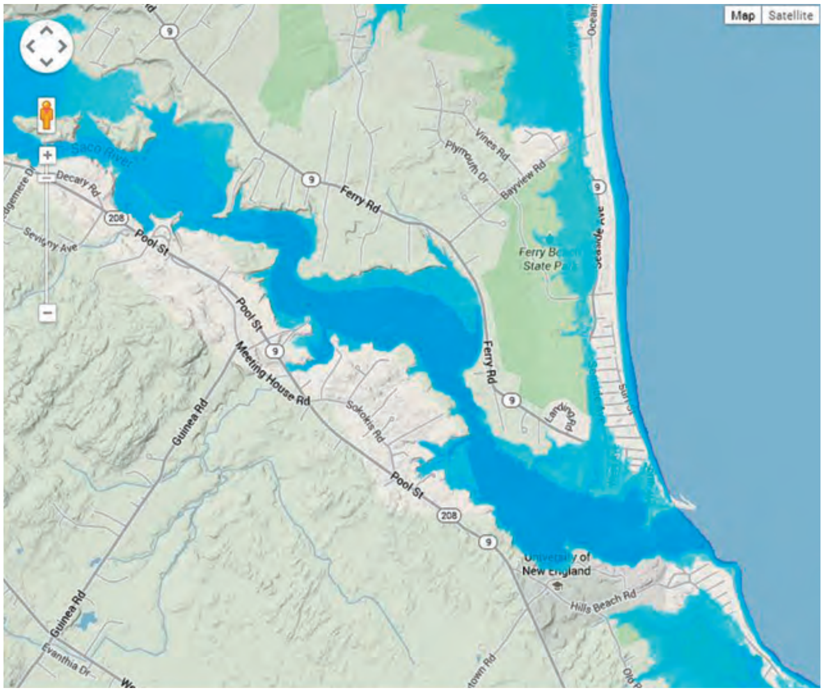

FIGURE 6 Map showing the modeled effects of storm surge during a major storm in 1978 plus a projected 3-ft sea level rise. Modeled using NOAA's Coastal Inundation Mapping Tool (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer).

What are some potential steps that could be taken to prepare Biddeford and Saco for the increasing effects of SLR?

Based on the results of our study of the effects of projected sea level rise on the Saco Estuary tidal marshes, we make the following recommendations to build on this preliminary work:

1. Discuss SLR model results with local Biddeford and Saco communities as a component of local climate change adaptation planning.
2. Survey marsh borders for barriers to inland migration of tidal marshes.
3. Create a localized, more accurate version of the NOAA SLR viewer that allows running multiple scenarios.
4. Model predicted low tide changes and effects on mudflats.
5. Model interaction of the invasive common reed (*Phragmites australis*) and sea level rise.

CONCLUSIONS

We made the following conclusions from our research on the effects of SLR on the Saco Estuary's tidal marshes:

- Roadways, seawalls, and natural ledges adjacent to tidal marshes will block many marshes from migrating inland as sea level rises.
- Because marsh migration will be blocked, tidal marshes will become smaller.
- Smaller marshes and the higher sea level will increase the vulnerability of Biddeford and Saco to storm surge damage.

ACKNOWLEDGEMENTS

Thank you to undergraduate student Samuel Peterson. Additional thanks to Mark Adams and Pam Morgan.

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CHAPTER 10

WATER QUALITY IN THE SACO RIVER

BY STEPHAN I. ZEEMAN AND TYLER SPILLANE

INTRODUCTION

What does water quality mean? Water quality means different things to different people, but it basically comes down to, how good is the water for living things in and around it? From a scientific standpoint we can measure water chemistry (what are its chemical components), biology (what organisms inhabit the water), or physics (what is its temperature, or is it stratified into temperature layers). From a human perspective we are often interested in aesthetic questions: does it look good, does it taste good, and does it smell good? Water quality is important because it impacts the health of humans and other living creatures that come in contact with it.

STUDY OBJECTIVES—WATER QUALITY

Our objectives for the water quality study were to answer these questions:

1. What are the levels of fecal indicator bacteria, nutrients, chlorophyll, and dissolved oxygen? Are any issues or parameters that should be monitored?
2. What do indicators of water quality tell us about the state of the Saco River?

RESEARCH DESIGN AND METHODS

Sampling

A total of 18 sites along the Saco River watershed from Crawford Notch, NH, to Biddeford, ME, were monitored for indicator bacteria. Sample collection occurred monthly from December 2010 to November 2012, with some additional data collected later. Fourteen sites were directly along the Saco River, while sites 3, 8, and 9 were small tributaries that feed into the river. Sites 15, 16, and 17 were in the estuarine portion of the river with variable salinity levels. Site 18 was at Biddeford Beach adjacent to the river in the Gulf of Maine. Sampling the entire length of the river throughout the year posed its challenges as can be seen in Figure 1.

FIGURE 1 Contrasting sample collections. Top left: Tyler Spillane sampling a partially ice-covered river in Conway, NH. Bottom left: sampling during spring flood at Limington Rapids. Right: sample collection during relatively normal river stage on Little Ossipee River near Limington, ME.

Fecal Indicator Bacteria

Total coliform bacteria and *E. coli* were determined with Colilert-18© and enterococci with Enterolert©, both from IDEXX laboratories. These methods are US EPA approved (Meyers et al. 2007). Samples were collected in sterile 120-ml bottles and volume adjusted to 100 ml. The bottles were kept on ice and in the dark until they reached the laboratory. Reagents were added to each

100-ml sample, thoroughly mixed, and poured into a Quanti-Tray®/2000, which are then heat sealed and incubated. The trays were incubated at 35±0.5°C for 18-22 hours for Colilert-18© and 24 hours or Enterolert©. Most Probable Number (MPN) is calculated from the number of cells that turn yellow (total coliform) or turn yellow and fluoresce under UV light (*E. coli* and enterococci).

Nutrients

Samples were collected in 200-ml polyethylene bottles, stored on ice for transport, and frozen until analyzed. Concentrations of phosphate (PO_4), nitrate + nitrite (NO_3+NO2), ammonia, and silicate (Si) were measured spectrophotometrically using prepackaged Hach chemicals (Hach Company, Loveland CO). For nitrogen compounds in this study, we report only nitrate plus nitrite. In most of our samples, ammonia was not detectable by our analysis techniques.

Chlorophyll

Chlorophyll *a* samples were collected in 200-ml polyethylene bottles and stored on ice for transport to the laboratory. Aliquots of 50-100 ml were then vacuum filtered at < 8 inches Hg onto Whatman GF/F glass fiber filters. The filters were ground with a Ten Broeck tissue grinder, transferred to conical centrifuge tubes, and extracted with 10 ml of 90% acetone for 24 hours in a freezer. The centrifuge tubes were then spun at 3,500 rpm for 10 minutes. The samples were analyzed with a Turner TD-700 fluorometer.

Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen were measured in the field with a YSI ProODO meter (YSI Inc., Yellow Springs, OH).

Rainfall and River Discharge

Rain data were accessed from the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) for sites 2, 15, 16, and 17. Discharge data for sites 2 and 7 were accessed from the US Geological Survey (USGS).

Land Cover

Land cover data was acquired from the National Land Cover Database through the Multi-resolution Land Characteristics Consortium (http://www.mrlc.gov/finddata.php). Future land cover was modeled using the IDRISI Land Change Modeler from Clark Labs (http://www.clarklabs.org/)

RESULTS AND DISCUSSION

What are the levels of fecal indicator bacteria, nutrients, chlorophyll, and dissolved oxygen? Are any issues or parameters that should be monitored?

Indicator Bacteria

Geographical distribution

Overall the Saco River met water quality standards for indicator bacteria. The geometric mean from each site was far below the required levels set by the US EPA criterion of 126 (Figure 2). The geometric means for *E. coli* numbers across 2 years show a high amount of variability as indicated by the large error bars. The figure shows overall higher levels of *E. coli* at sites 15,16, and 17 (which are all in the estuarine portion of the river and located close to the population centers of Biddeford and Saco) and then a return to lower values at site 18 (the beach site). The greatest variability also is found at these sites, and the results also show that a sample from site 15 exceeded

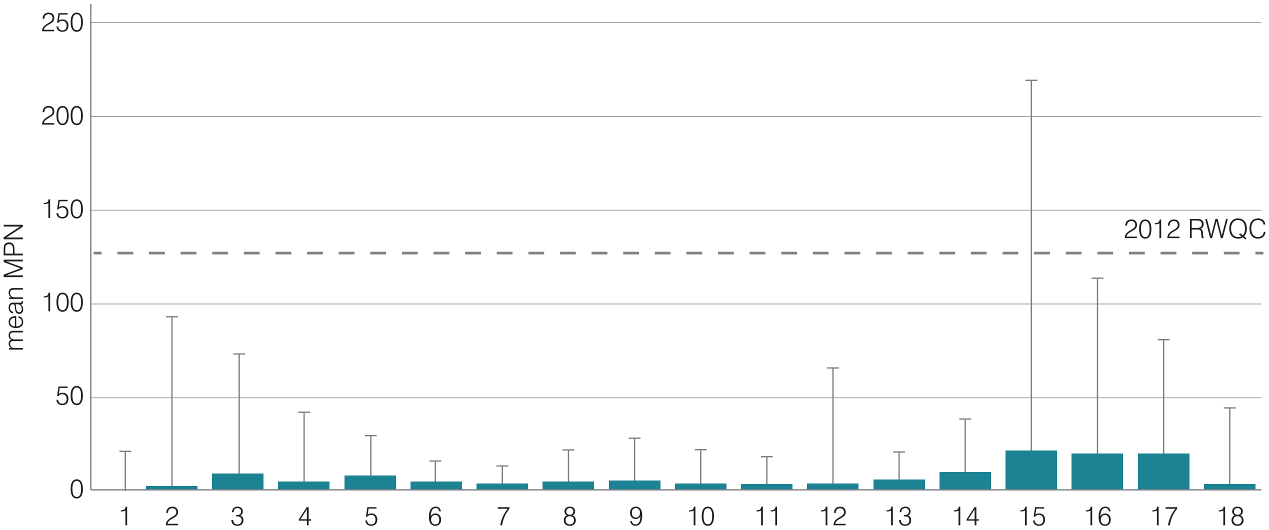


FIGURE 2 Geometric mean of MPN of *E. coli* at each station across 2 years of monthly sampling. Bars indicate standard deviation.

the recommended US EPA levels. Similar results were obtained for total coliform numbers, where the data showed an overall increase in MPN for sites 15, 16, and 17, and a subsequent decrease again at 18. Total coliform and *E. coli* data are highly correlated as shown in Figure 3. Total coliform data is not discussed further in this report for two reasons: (1) the relationship shown in Figure 1 means that no new information would be gleaned from the total coliform numbers and (2) these bacteria are potentially from additional sources. In other words, they are not as specific an indicator as are *E. coli* of fecal contamination. Indeed, total coliforms include bacteria in soils and plants as well as those from the intestines of warm- and cold-blooded animals.

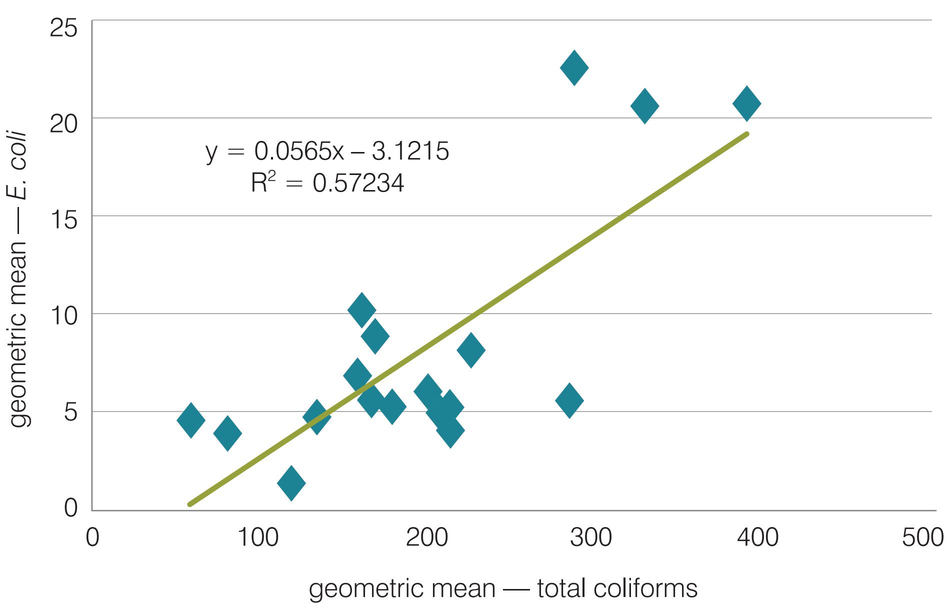


FIGURE 3 Correlation of MPN of Total Coliforms and *E. coli*. The regression equation and R^2 are also shown.

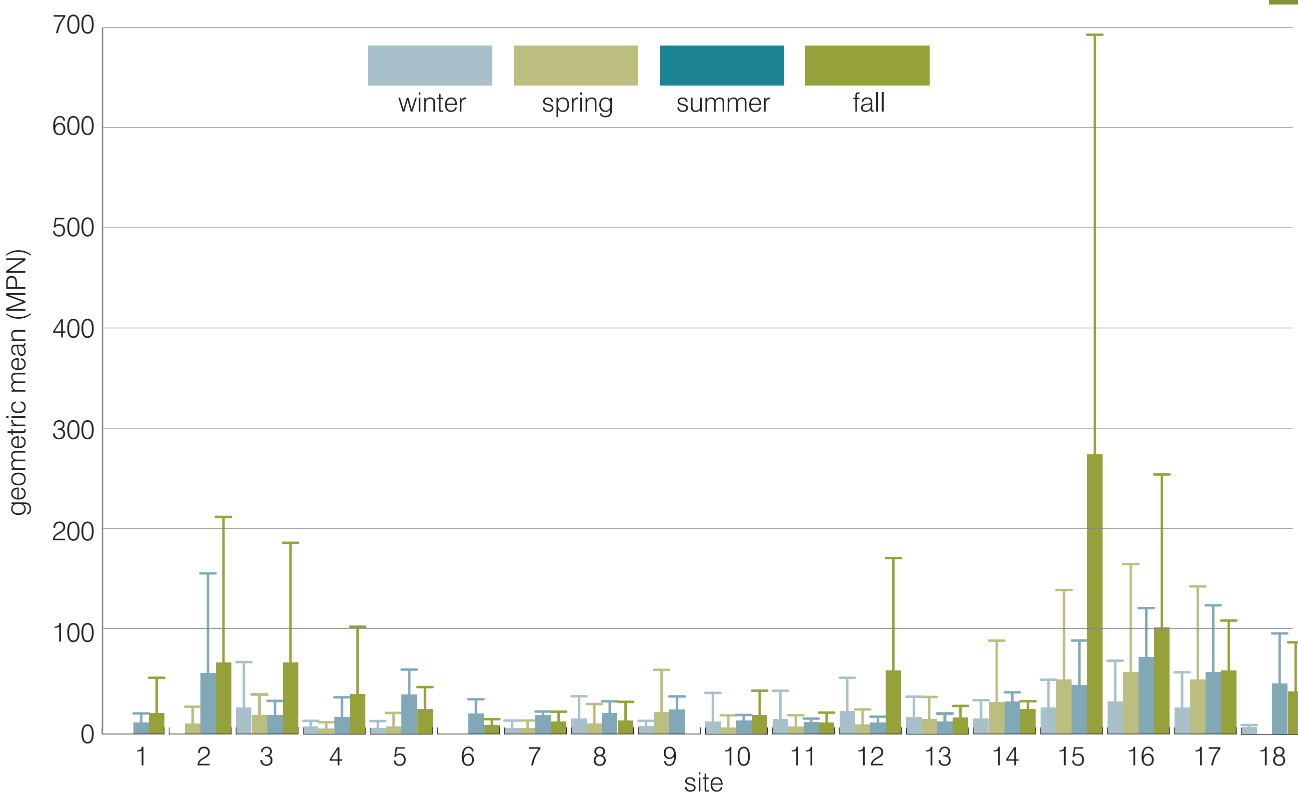


FIGURE 4 Winter, spring, summer, and fall (DJF, MAM, JJA, SON) geometric mean *E. coli* MPN at sites along the Saco River. Bars indicate standard deviation.

Seasonal change

The amount of indicator bacteria in the water changes with the season (Figure 4). As might be expected, winter (Dec/Jan/Feb) and spring (Mar/Apr/May) have the lowest values. While fall and summer (June/July/Aug) have the highest levels of *E. coli*, there is no significant difference between the two ($p=0.21$). Levels of *E. coli* in the summer and spring are significantly different ($p<0.1$), as are levels in summer and winter ($p<0.00$). Spring and winter levels are not significantly different ($p=0.33$). The level in fall (Sept/Oct/Nov) is significantly higher than both winter ($p<0.05$) and spring ($p=0.05$) values. That fall had the highest *E. coli* numbers is perhaps somewhat surprising.

Population density

We attempted to look at relationship of indicator bacteria to population by aggregating sites near the upper end of the river (low population, but commercialized), middle reach (low population, mostly agriculture), and lower end of the river (higher population, and more urbanized).The indicator bacteria levels at the upper end (sites: 1-5) and middle reach (6-12) of the river are not significantly different from each other ($p=0.71$). However, the values at the lower reach sites (13-18) are significantly higher than both the upper ($p<0.05$) and middle ($p<0.05$)

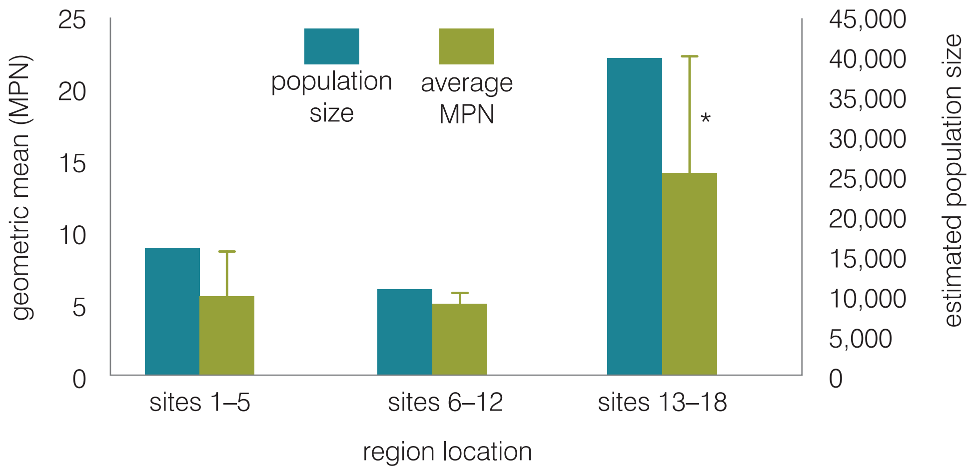


FIGURE 5 Relationship between population size and MPN of *E. coli* at grouped sites. Bars for the MPN are the standard deviation.

reach sites. The population size in the lower reach is approximately 40,000 people, the middle reach is about 11,000 people, and around the high reach about 16,000 people (Figure 5). The figure shows that areas with high *E. coli* also had a higher population, and low MPN areas had a lower surrounding population.

Rainfall

Regression analysis was performed between *E. coli* (MPN) and precipitation (cm) at each available site with no lag in time, and with rainfall occurring at lag times of 1,2, or 3 days before sampling. Rainfall data analysis produced no significant results. Regression analysis of precipitation (cm) against *E. coli* at site 2 for no lag period produced an R^2 of 0.14, similar results were found with a 1-day ($R^2 = 0.10$), 2-day ($R^2 = 0.02$), and 3-day ($R^2 = 0.01$) lag period after precipitation. These results indicate that precipitation alone was not a very good predictor of *E. coli* numbers.

River discharge

Regression analysis was also performed with *E. coli* (MPN) and discharge rate (m^3/sec). Multiple regression analysis was performed with *E. coli* against precipitation (cm) and discharge (m^3/sec). Discharge rate (m^3/sec) produced analogous results with a low R^2 of 0.001. Multiple regression analysis between precipitation (cm) and discharge (m^3/sec) against MPN of *E. coli* resulted in an R^2 of 0.16. As with rainfall, discharge volume is not a good predictor of *E. coli* numbers.

Chlorophyll *a*

The chlorophyll *a* data were not especially remarkable, with most values at <15 μg/liter (Figure 6). This puts the river in the range of oligotrophic to mesotrophic (Dodds et al. 1998). However, some of these values are classified as less than desirable (7-15 μg/l) by the State of New Hampshire for rivers, and potentially a nuisance (>15 μg/l). The larger spikes are, at present, unexplained. However, there are very few of these. There is a seasonal pattern of chlorophyll that coincides

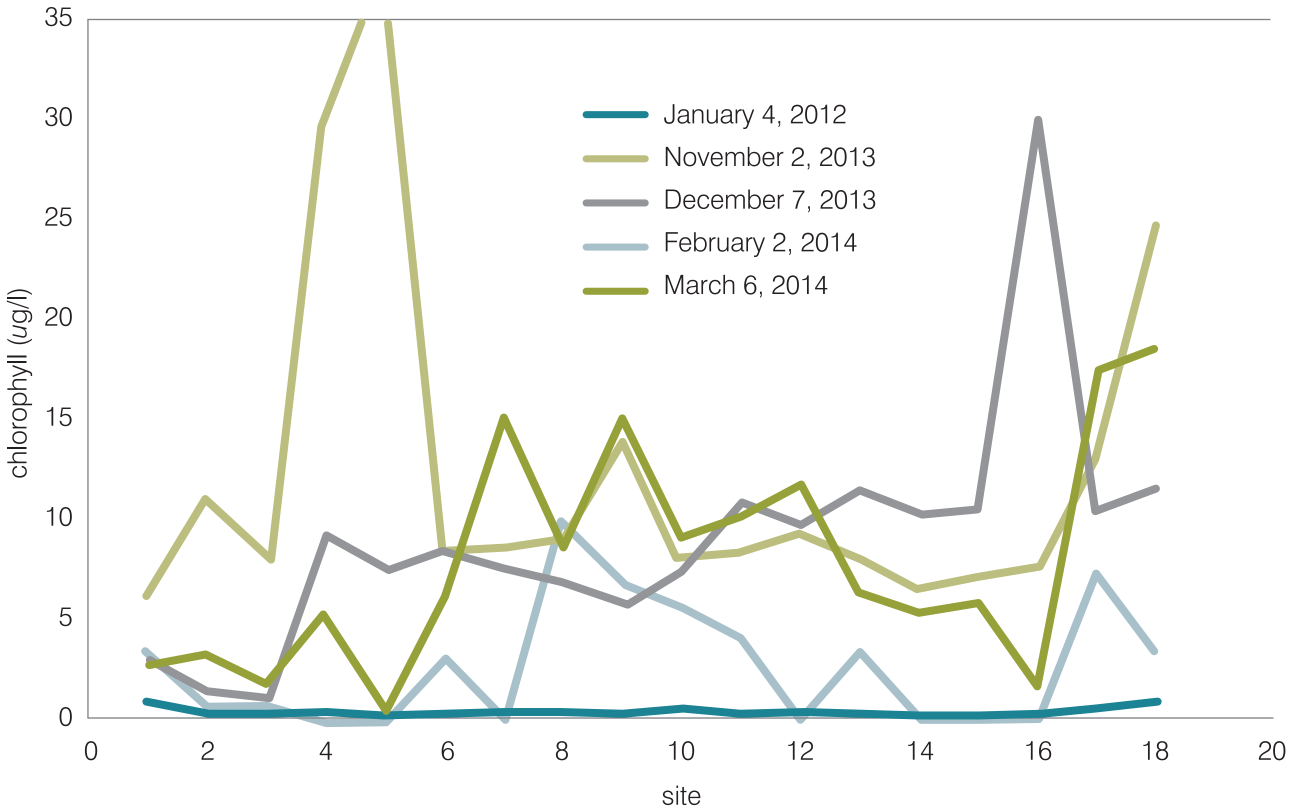


FIGURE 6 Chlorophyll *a* concentrations along the Saco River.

generally with the growing season but apparently extends late into the year (Figure 7). The reason for this extended growing season is unclear. One explanation could be that the dataset is limited and may be missing some key months during the chlorophyll sampling. The November sampling had two very high values at stations 4 and 5 in the Fryeburg, ME, area. With leaf fall in autumn, decreased shading could potentially lead to higher phytoplankton growth. Phytoplankton

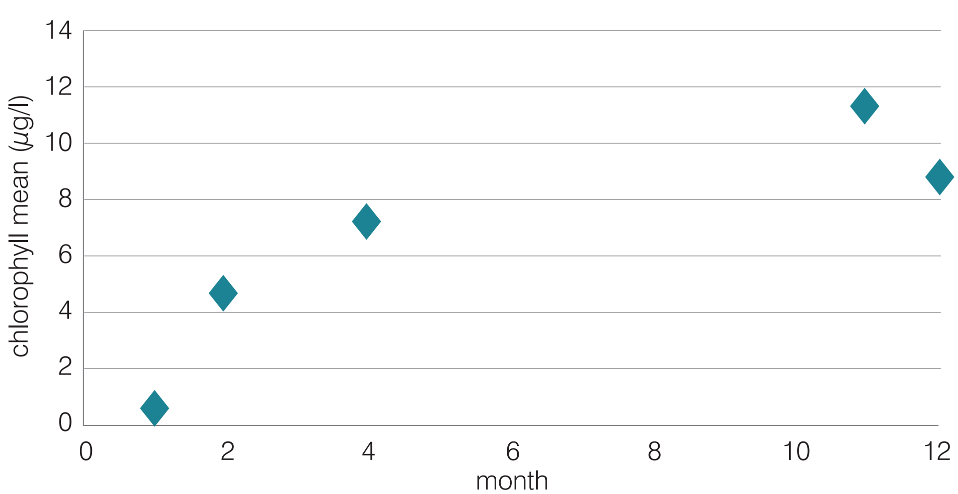


FIGURE 7 Seasonal pattern of mean chlorophyll concentrations.

species composition could also be changing, and more tolerant species may be able to grow during the late fall and early winter (Read et al. 2014). Another possibility is that precipitation tends to be higher during October, November, and December, which might affect resuspension of phytoplankton from the sediments or flush them into the main stem of the river from the surrounding marshlands.

Nutrients

Nutrients were not sampled as frequently, and only a limited dataset is presented. Nutrient concentrations were variable, but not out of line with normal surface waters.

Nitrate

Nitrate + nitrite concentrations were generally less than 0.2 mg/L, with lower values in the middle and lower reaches of the river (Figure 8). Monthly averages are 0.07, 0.08, 0.12, 0.07,and 0.05 mg/L for Jan, Feb, Mar, Apr, and Nov, respectively. The data for March and April are somewhat elevated in the upper reaches of the river. These values are far below the critical levels of concern for human health set by US EPA, and below what the Cary Institute states is normal for rivers (1 mg/l). They are also below US EPA reference values in Subregion 58 (0.16 mg/l) and Subregion 59 (0.31 mg/l).

Phosphate

Phosphate concentrations were also low, with two exceptions (Figure 9). These are typical of the region as well. Monthly averages were 0.03, 0.05, 0.06, 0.07, 0.06, and 0.14 mg/L for Nov 2011 and Jan, Feb, Mar, Apr, and Nov 2012, respectively. Since we only measure orthophosphate and not total phosphorus, our numbers are hard to compare with some of the criteria. The Cary Institute states that unpolluted

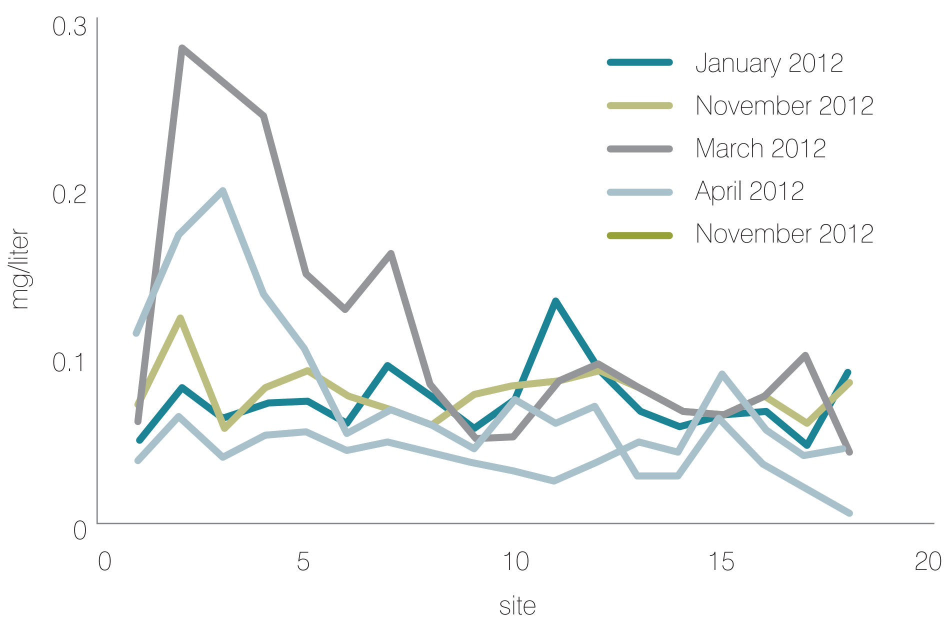


FIGURE 8 Nitrate plus nitrite concentrations (mg/L) along the Saco River.

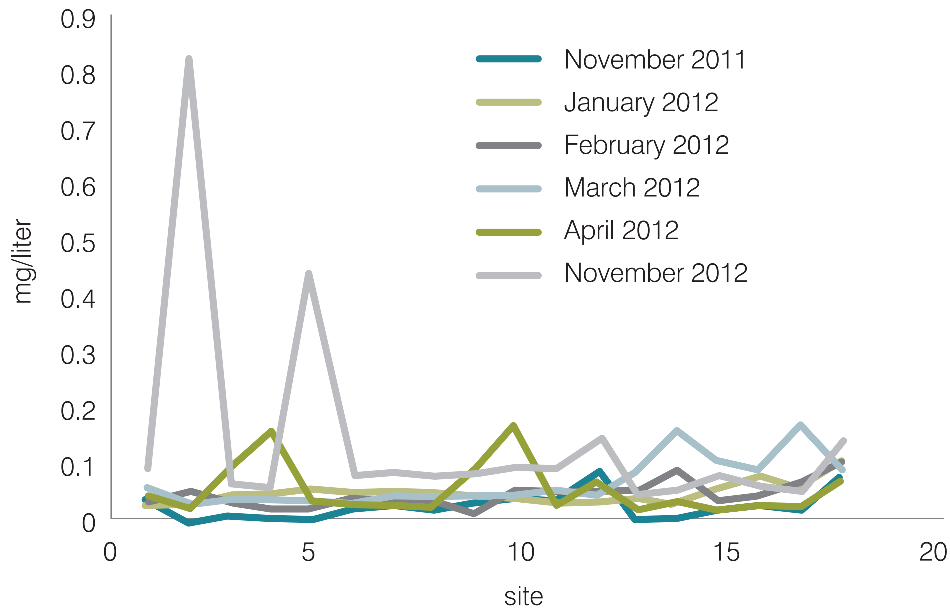


FIGURE 9 Phosphate concentrations (mg/L) along the Saco River.

waters are in the range of 0.01- 0.03 mg/l orthophosphate, which is less than most of our values, indicating there is some impact here. Even though our measured values represent only a portion of total phosphorus, they are greater than what the State of New Hampshire considers desirable for total phosphorus in rivers; >0.051 is excessive and may be a potential nuisance (http://des.nh.gov/organization/divisions/water/wmb/vrap/documents/wq-resultsinfo.pdf).

US EPA also conducted some nutrient sampling of the waters of Saco Bay on July 2, 2010. Again, these data show nutrient concentrations that are within expected levels for unpolluted waters.

Dissolved Oxygen

DO levels along the Saco River remained fairly high, between 90-105% saturation throughout our measurement period (Figure 10). Additional measurements made by the Saco River Corridor Commission also show that DO levels remain reasonably constant ranging from 6.5 mg/L–10.5 mg/L depending on location, with an average of 8.0 mg/L (SRCC 2010). The exceptions are problematic tributaries of Swan Pond Brook and Thatcher Brook where mean DO saturations are in the 80% or 60% level (Saco River Corridor Commission, http://srcc-maine.org/water-quality-monitoring/water-quality-data/).

Water Temperature

Water temperature of the Saco River varies depending on location and season. The surface may freeze above site 15 in winter, while summer water temperatures ranging from 20-25°C until the river reaches cooler ocean water. The estuarine sites (15-17) are also known to freeze on the surface, especially at site 15.

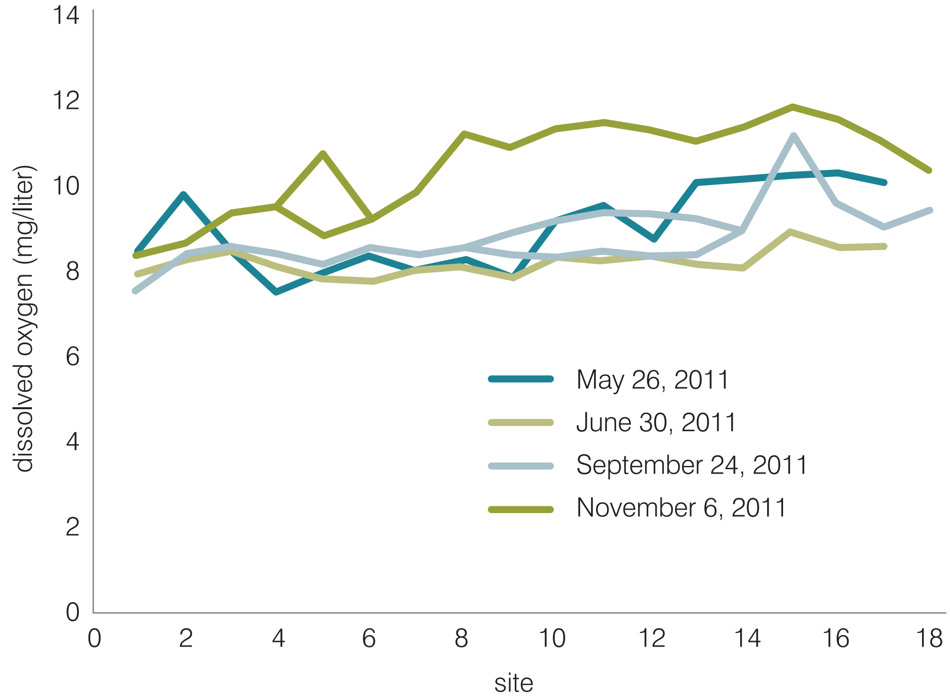


FIGURE 10 Dissolved oxygen concentrations (mg/L) along the Saco River.

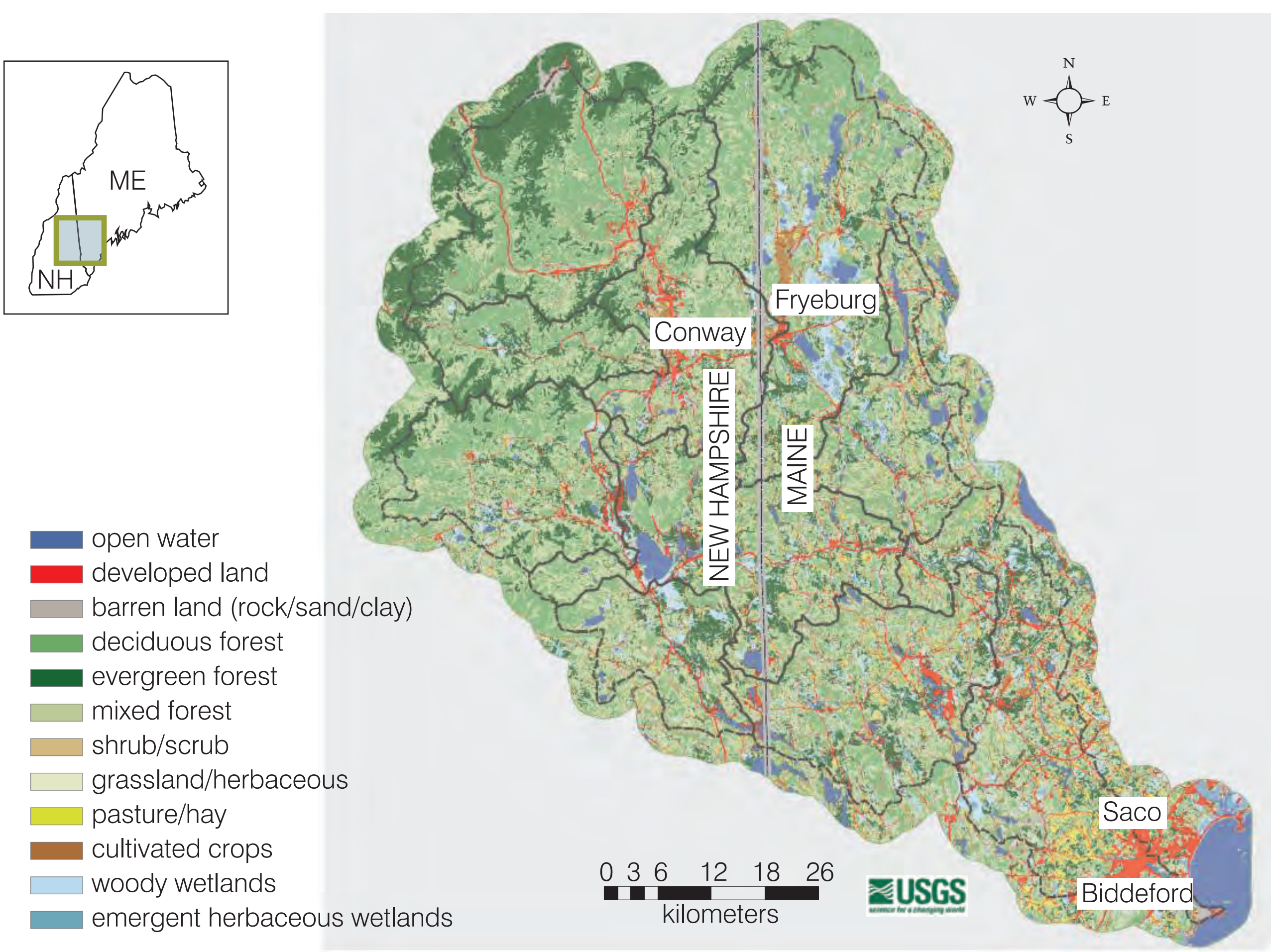


FIGURE 11 Major land cover types in the Saco River watershed.

Growth and Development Model

The Saco River watershed contains a mixture of land cover types (Figure 11). Most of the area is low-intensity developed forested land, with only a minor portion of developed land. The majority of the development is in the coastal area around the cities of Biddeford and Saco in Maine, with some in the resort region around North Conway, NH.

The population in southern Maine has increased modestly, between 5 and >25% in the last decade (Figure 12), while North Conway, NH, has seen a 13.5% increase in population from 2000-2010 (http://www.city-data.com/). These data encouraged us to look at the development trajectory in the region.

To examine future development potential, we used IDRISI Land Change Modeler to predict changes in the North Conway area. Starting with actual land cover data for 1992, 2001, and 2010 from USGS, we modeled what land cover would be in 2030 (Figure 13). A significant expansion of the developed area (red) can be seen throughout the sequence.

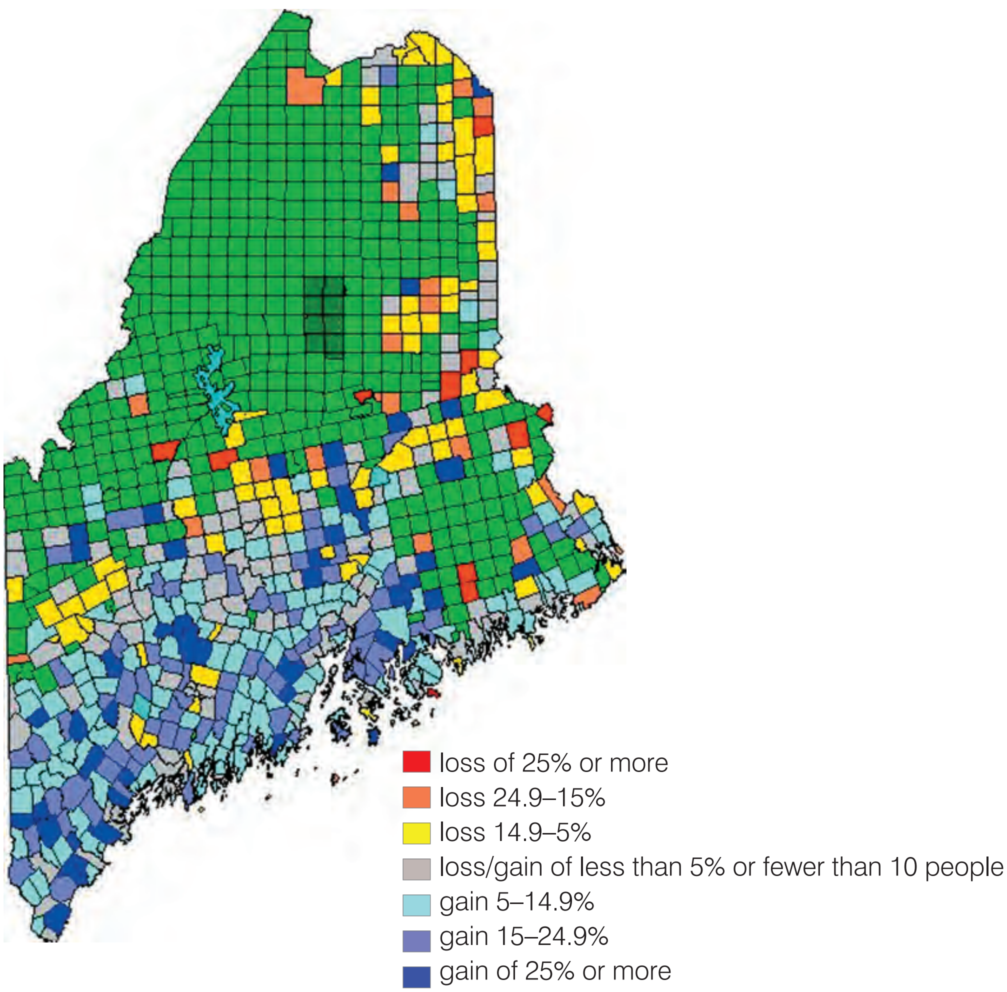
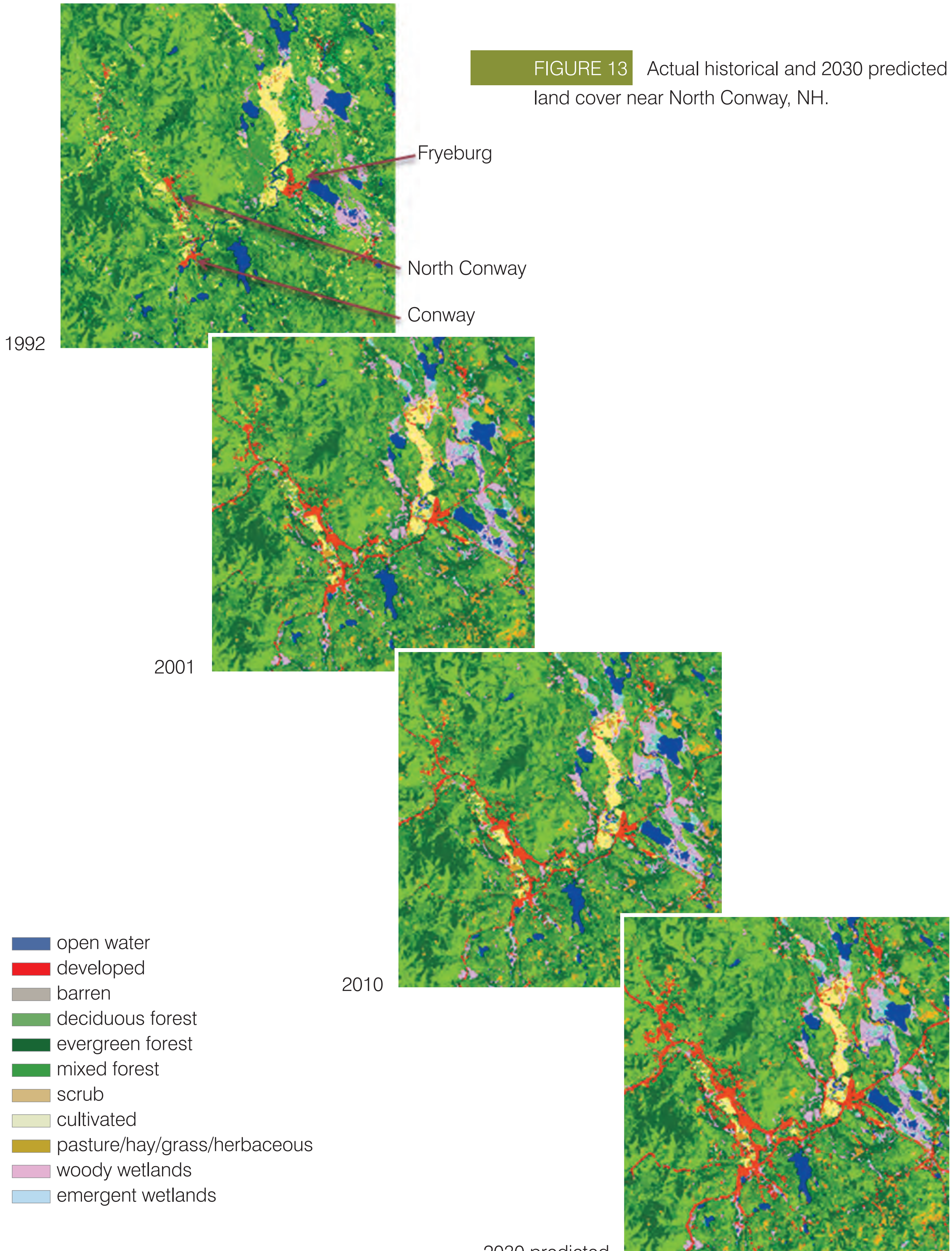


FIGURE 12 Population change in Maine towns between 1990-2000. (Source: http://maineanencyclopedia.com/population-since-1741/

FIGURE 13 Actual historical and 2030 predicted land cover near North Conway, NH.



What do indicators of water quality tell us about the state of the Saco River?

According to the US EPA Watershed Assessment Report for 2010 (http://ofmpub.epa.gov/tmdl_waters10/attains_watershed.control), the Saco River is in good condition except at the Biddeford-Saco area, where it is impaired due to high *E. coli* counts. Also identified as sources of *E. coli* are a combined sewer overflow (CSO) at Bear Brook in Saco, Thatcher Brook in Biddeford, and Swan Pond Brook at South Street in Biddeford. The state as a whole has made significant progress on reducing discharges from CSOs (Breau 2013). Even as precipitation is increasing in the Northeast, discharges from CSOs have been reduced. Biddeford currently has nine CSOs that empty into the Saco River and one that drains into Thatcher Brook. The City of Saco has three CSOs that empty to the Saco River and one to Bear Brook. Over the period 1987-2012, Biddeford has lowered its annual CSO flows by 80% and Saco by 98%.

CONCLUSIONS

We made the following conclusions based on our study of water quality and development in the Saco River watershed:

- Aside from occasional outliers in the data, the Saco River watershed remains below the recommended fecal indicator bacteria (specifically *E. coli*) levels for recreational waters set by US EPA. While this is a positive result in terms of ecosystem health of the Saco River, continual monitoring of fecal indicator bacteria is still recommended based on its highly variable nature. The results also indicate that other factors than those reported here affect the variability of indicator bacteria. Further study of fecal coliform in sediment and variable human population impacts should help make these causes better understood.
- Other water quality criteria measured also showed levels within the very good to excellent range. Chlorophyll levels were mostly $<$15 mg/l, indicating non-bloom conditions. Nutrients were in the range considered to be below or close to background levels for natural waters. Dissolved oxygen measurements were near saturation for all measurements.
- Our modeling of future land cover suggests that increased development is very likely. This is a concern especially for the headwaters of the Saco River watershed. Some contaminants not included in this study, such as mercury and new and legacy pollutants, should be studied further. These pollutants include toxins and endocrine disruptors that have the potential to harm aquatic life as well as human health.

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