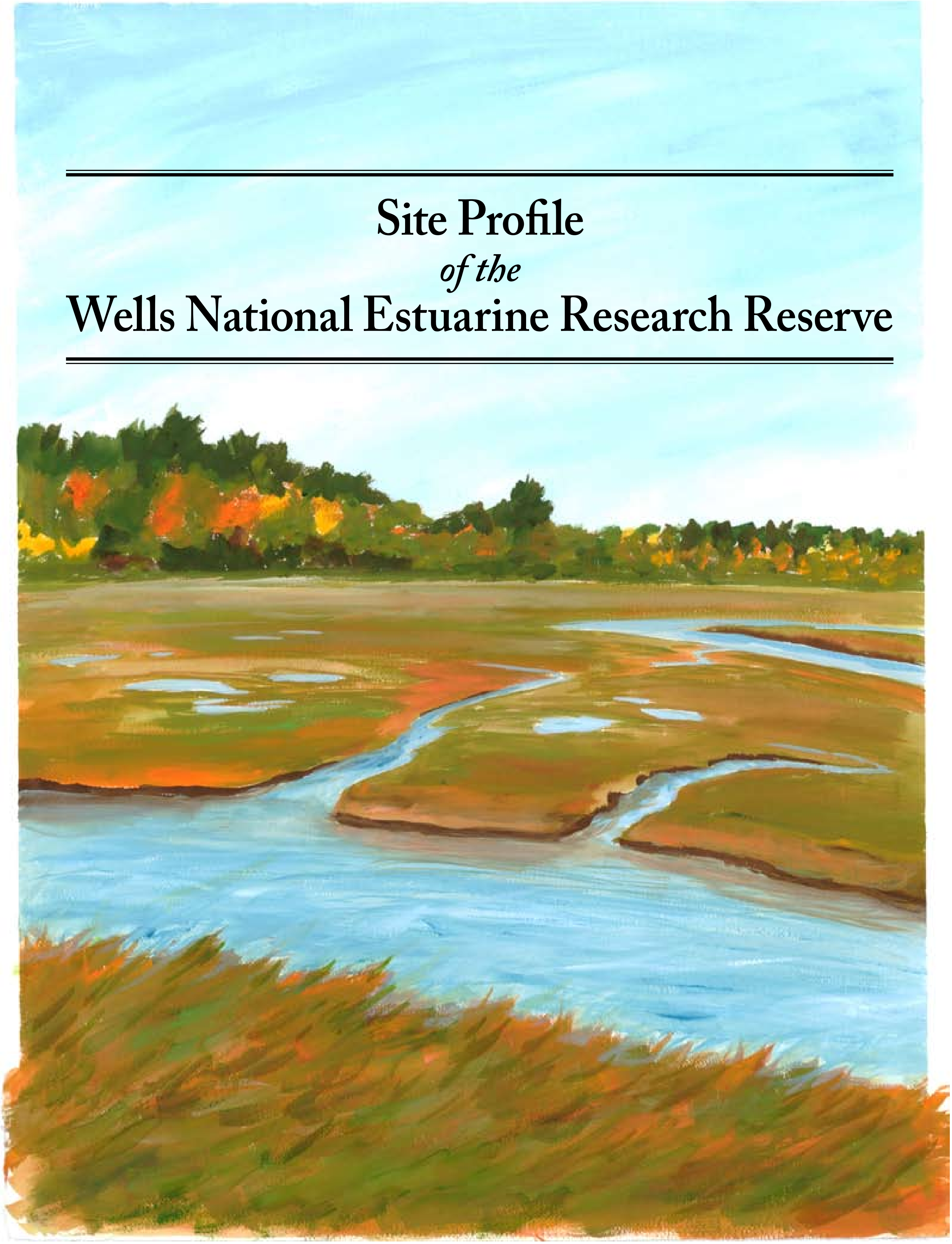
Site Profile

of the

Wells National Estuarine Research Reserve



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Wells National Estuarine Research Reserve

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Wells National Estuarine Research Reserve (Wells NERR) is a partnership between the US Department of Commerce, National Oceanic and Atmospheric Administration, and the State of Maine, Wells Reserve Management Authority (RMA). The RMA consists of the Laudholm Trust, the US Fish and Wildlife Service, the Maine Department of Conservation, the Maine State Planning Office, and the Town of Wells.

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January 2007

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Contributors

Britt Argow is an assistant professor at Wellesley College in Massachusetts. Her research focuses on sedimentary processes on coastal wetlands, with special emphasis on geomorphologic, seasonal and climatic variation in sedimentation patterns. The Wells National Estuarine Research Reserve is a long-term monitoring site in this program of study. She is also involved with geoscience education and outreach initiatives, locally and nationally, and in developing and promoting the new pedagogy of science education. She completed her doctorate in 2006 in coastal sedimentology at Boston University, and her Masters in micropaleontology and sedimentology at Stanford University in 1998.

Rob Baldwin received his Ph.D. in vernal pool ecology from the University of Maine working with Aram Calhoun and Phillip deMayandier. Rob conducted his doctoral field research in York County in southern Maine. He stayed at Laudholm Farm, and studied vernal pools in four townships. His research project was greatly enhanced by frequent interactions with WNERR staff. Timothy Dexter, Lori Johnson, Lesley Latt, and Daniel Zeh are candidates for MS degrees in Conservation Biology at Antioch University New England. Each is pursing thesis research in wetland ecology or herpetology, and conducted field, GIS, or literature research for this chapter.

Susan Bickford received her Bachelor of Science Degree in Environmental Science in 1997 and has been a GIS / Natural Resource Specialist at the Wells Reserve since 1999. She provides local conservation organizations with natural resource mapping support and is an avid photographer who contributed many of the maps and photographs for this document. Susan recently completed her seventh year as a volunteer for the Maine Damselfly and Dragonfly Survey and her tenth year as a volunteer for the North American Amphibian Monitoring Program.

Caitlin M. Crain served as an Americorp Watershed Leader through the Wells National Estuarine Research Reserve, developing a volunteer stormwater sampling protocol in southern Maine to identify sources of fecal bacterial pollution closing coastal clam flats, and later became a graduate fellow at Wells NERR and received a Walter B. Jones memorial award from NOAA for excellence in coastal and marine graduate research. Caitlin's research focuses on understanding the influence of estuarine salinity gradients on salt marsh plant communities. She recently completed her doctoral dissertation in the Department of Ecology and Evolutionary Biology at Brown University.

Christopher Cayce Dalton is an associate researcher and educator at the Wells National Estuarine Research Reserve. His experience includes coordinating the System Wide Monitoring Program at the Reserve. His research has focused on tracking sources of bacterial contamination, fish and shellfish population studies, eutrophication of coastal waters and working with volunteer monitors. He received his bachelors degree in Environmental Science from the College of William and Mary.

Michele Dionne has served as Research Director of the Wells National Estuarine Research Reserve since 1991. During that time the program has developed a strong focus on the ecology of estuaries and coastal marshes in the Gulf of Maine, the food webs and species that depend on them (especially fish), and the processes by which they are degraded and restored. Program staff work closely as mentors with undergraduate interns, graduate students and post-doctoral fellows, providing hands-on research training in the field and laboratory. Dionne holds adjunct faculty appointments at the University of New Hampshire, the University of Maine, and the University of Southern Maine. Prior to her current position at Wells NERR, she held a research faculty position in the Biology Department at Virginia Tech. Her graduate education includes an M.S. from the University of North Carolina-Chapel Hill (Zoology) and a Ph.D. from Dartmouth College (Biology), with a B.A. in Biology from Bates College in Maine.

James Dochtermann is a research associate at the Wells National Estuarine Research Reserve. His experience includes investigating fish communities and habitats from Gulf of Maine estuaries and their associated watersheds to offshore marine areas. He also assists with the NERR System Wide Monitoring Program. James received his B.S. in Natural Resources and Marine Science from the University of Maine, Orono. He has created a large collection of his own illustrations based on fishes and habitats of the Gulf of Maine, which he has provided for numerous documents and publication for Gulf of Maine-related research, education and stewardship.

Charles Lubelczyk is a field biologist with the Maine Medical Center Research Institute in South Portland, Maine, and a volunteer with the Wells National Estuarine Research Reserve. His experience includes work as an educator and taxonomist. His research has focused on the ecology of vector-borne diseases, particularly Lyme disease and West Nile virus, and he has a strong interest in the relationships between arthropod vectors, their hosts and their habitats. He received a BA in Wildlife Management from the University of New Hampshire.

Matthew McBride has been a GIS Specialist at the Wells National Estuarine Research Reserve since January of 2003. His duties include providing mapping support for area GIS users, training members and volunteers in the use of the GPS and Trimble Total Station survey equipment. Other duties include assisting researchers in spatial analysis of GIS data and aerial photographs, groundwater and estuarine circulation modeling and field data collection. Matthew has extensive training in digital mapping including classes in GPS, GIS and Conservation Geography at the University of Southern Maine and the University of New Hampshire. He received his Bachelor of Arts Degree in Geography/Anthropology from the University of Southern Maine and is currently a graduate student at the University of New Hampshire pursuing a Master's Degree in Environmental Conservation.

Jeremy Miller is a research associate and coordinator of the System Wide Monitoring Program at the Wells National Estuarine Research Reserve, and also works as Extension Associate for Maine Sea Grant and the Southern Maine Beach Profiling Program run through the University of Maine Cooperative Extension. He is involved with the NERRS system on a national level as well, having been named the North East Regional Telemetry Support Technician for the Centralized Data Management Office. Jeremy's research includes benthic invertebrate community structure and their use as indicators of ecosystem health, and fish utilization of marsh habitat in New England fringing and meadow marshes. Jeremy received his Bachelors of Science in Environmental Science and Marine Biology from the University of New England in Biddeford, Maine and has been with the Reserve since 2002 when he started work as an intern on several projects.

Kate O'Brien is the Wildlife Biologist at Rachel Carson National Wildlife Refuge in Wells, Maine. She has over ten years of professional wildlife management, conservation and monitoring experience. She is particularly interested in non-game and endangered wildlife conservation, sustaining native plant communities, working with private landowners and volunteers and long term conservation planning. As a volunteer, she serves on the board of the Great Works Regional Land Trust. She graduated from the Yale School of Forestry with a Masters degree in Wildlife Ecology in 1995 and with a undergraduate degree in Communications with a minor in Wildlife and Fisheries Science from the University of Massachusetts in 1992.

Martin ("Tin") Smith has been associated with the Wells National Estuarine Research Reserve since its creation in 1986 and an employee since1996. He has been Stewardship Coordinator since 2002. He works with land trusts, watershed coalitions and communities to increase the amount of protected lands and improve water quality. He provides field support to researchers and the System Wide Monitoring Program. He participates in the Coastal Training Program at the Reserve, helping transfer research results to coastal resource decision makers. Tin received a BS in Environmental Science from the University of Massachusetts at Amherst.

Megan Tyrrell was a postdoctoral research associate at the Wells National Estuarine Reserach Reserve, and is now a postdoctoral associate at the NOAA Fisheries Northeast Science Center in Woods Hole. Her research at the reserve focused on introduced species and their impacts in salt marsh and other coastal habitats. She completed her undergraduate education at Macalester College in St. Paul, Minnesota and her graduate degrees at the University of New Hampshire in Durham, New Hampshire.

Hannah Wilhelm is a salt marsh ecology intern at Wells NERR, and wishes to thank Michele Dionne and all the other authors for the opportunity to learn about the Reserve. Hannah recieved her BA in Chemistry from Bryn Mawr College in 2005. Before coming to the Reserve, she helped introduce an inquiry-based curriculum as an instructor in Bryn Mawr's introductory physics laboratory, and worked as an environmental educator in Vermont and Pennsylvania.

Martin Johnson Heade (American, 1819-1904), Newburyport marshes: passing storm, 1865 – 1870. Permission requested from the Bowdoin College Museum of Art, Brunswick, Maine.

Inhabitants of the Gulf of Maine region have long appreciated the productivity of coastal marshes, New England's magnificent native grasslands. Photo Wells NERR.

Preface

This is the hay that no man planted,
This is the ground that was never plowed,
Watered by tides, cold and brackish,
Shadowed by fog and the sea-born cloud.[1]
— Elizabeth Coatsworth
1893-1986

The Wells National Estuarine Research Reserve is many things to many people. It is a breathtaking haven for those who seek the beauty and serenity of natural coastal landscapes. It is a place to wander among the many buildings of an historic farm, stepping back through generations. It is a place where we can be grateful for the efforts of visionary citizens of York County (and beyond), and the Reserve's non-profit partner, the Laudholm Trust. Together they continue to work hard and long to protect and transform this piece of earth — from fallow farm to field classroom and laboratory. It is a place where volunteers, visitors, students, educators, artists, natural resource managers, planners, policymakers, and scientists come to decipher challenging coastal dilemmas and unknowns. Their contributions merge with the work of the Wells NERR staff to bring human and natural communities closer together, benefiting all. Through the determined and impassioned work of all those connected with Maine's only National Estuarine Research Reserve, our coast's increasingly vulnerable natural communities will better survive. Indeed, we dare to hope that, ultimately, they will thrive.

— Michele Dionne, January 2007

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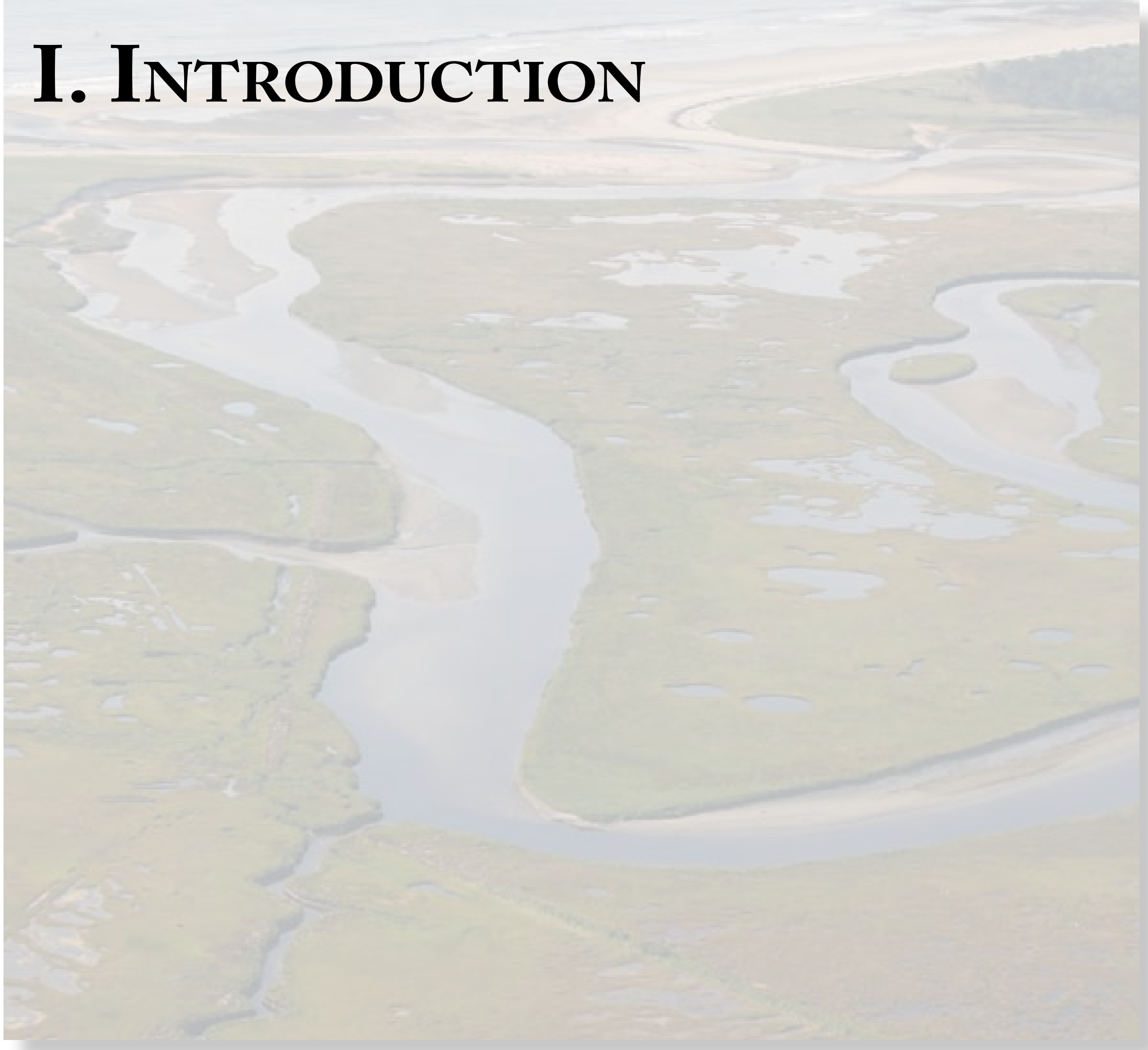
[1] Coatsworth, E. 1936. Salt Hay. Woman's Home Companion vol. 63, p. 35. Permission has been requested.

I. INTRODUCTION



CHAPTER 1

Introduction

CHRISTOPHER CAYCE DALTON

Maine's coast contains treasures of ecology, tradition and natural beauty. Hidden among the fragile reeds of its salt marshes are innumerable crossroads. From the ferry crossings that tied together a narrow, rough highway in the seventeenth century, to the biological intersection between spawning and adulthood for every catadromous and anadromous fish, to the point where the continent, river, ocean and sky all touch and intermingle, to the myriad of other symbolic and physical meeting points, countless worlds interlock in a Maine estuary. The Wells National Estuarine Research Reserve is home to two such estuaries.

ESTUARINE TYPE CHARACTERIZATION

Both the Webhannet and Little River estuaries were formed in the shelter of barrier beach spits and for this reason are termed "back-barrier marshes." Although they are among the largest salt marshes in Maine, they are considered small when viewed in a national or international context. They are dominated by strong tidal currents due to the large tidal range in the Gulf of Maine. The Webhannet Estuary generally contains well mixed, marine-salinity water, due to a small watershed, small freshwater inflow and a shallow basin which drains almost completely during low tide. The Little River is likewise tide-dominated, but a much larger drainage area funnels more fresh water inflow into a smaller marsh and channel, generating lower salinities and partial stratification of the water column.

HABITATS

Wells NERR encompasses three broad habitats types—wetlands, upland and beach—each containing a variety of environmental conditions. The diversity, large size and close vicinity of these habitats makes for an ecologically rich area, a setting which has become exceptionally rare along the coast of New England. The impressive diversity of habitats is actively protected and managed by the Reserve.

The wetlands of Wells NERR include salt marsh, red maple swamp, shrub swamp and brackish marsh. The 1,200 acres of salt marsh is the dominant habitat type at the Reserve. Complex plant associations, intricate drainage channels, extensive marsh pools, and regular inundation by tides mark this high energy habitat. This intertidal zone bears the marks of its diverse geologic history, with mud flats, fine to coarse sands, to cobble and boulder beaches. Resident and migrating fish and birds make their diets of the invertebrates that inhabit this area. These marshes formed behind double spit barrier beaches over the past 3,000 to 4,000 years. Early

European settlers valued them as ready-formed, bounteous meadows in an otherwise adverse environment.

Red maple swamp and floodplains are found along the Merriland River, Branch Brook and between Wells NERR campus and the salt marshes. Alder and winterberry holly dominate the understory, while sedges, ferns and wetland herbs form an herbaceous layer. Where freshwater species are able to intrude, a shrub swamp habitat forms, occurring in the upper reaches of the Little River and in areas of stagnant water where flow has been restricted. North of Route 9 is an area where saltwater and freshwater plant species intermingle. Another habitat, brackish marsh, has formed on the north side of Drakes Island Road, where flow historically has been restricted between the open marsh and a tributary channel. This area is currently subject to restoration efforts, where a self-regulating tide gate has been installed.

The uplands include both fields and woodlands. Before European settlement in the middle 1600's, oak-pine forest dominated the area which is now the Reserve. These forests were cleared for timber and fuel, and maintained as fields for farming and defense. Over the past two centuries, farms have been abandoned, making second-growth forest the most common land cover in the region, and threatening species which depend on open and semi-open land cover. About 90 acres of fields are mown to maintain grasslands, with two adjacent fields undergoing early succession with shrubs such as barberry, honeysuckle, bayberry and pasture rose. Abandoned apple trees and hawthorn trees line the edges of these transitional areas. Besides recalling Laudholm Farm's more than three and half centuries of agricultural heritage, these lands provide open and semi-open habitats essential to the grassland-nesting birds and other ani-

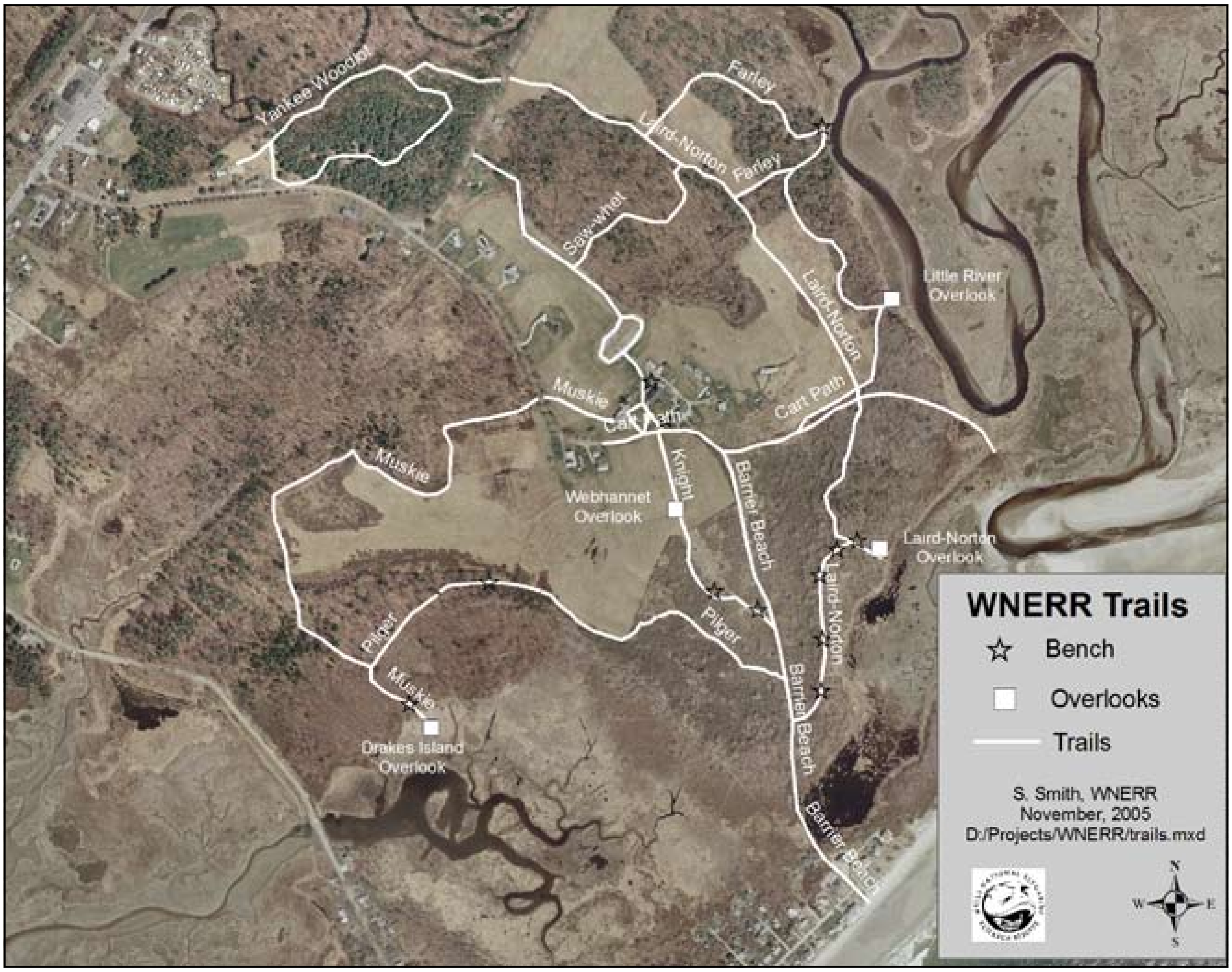


Figure 1-1: Wells NERR offers seven miles of hiking and cross-country skiing trails, with several overlooks onto the esuary and ocean.

mals that have become scarce in other parts of the New England coast.

In the northern portion of the Reserve is an oak-pine forest with a significant red maple component and other species intermixed. Heath shrub, in particular blueberry, dominate the understory. Mixed second-growth forest also occurs on site, where formerly cleared areas have been abandoned. Beaches and dunes form the third broad habitat category. Virtually all of the beaches in southern Maine have been extensively built upon. Laudholm Beach is an exception, an undeveloped stretch of vegetated dunes and smooth sand which flanks the entrance to the Little River. This beach consists of a low, partially stabilized foredune near the mouth of the river, stable backdunes and an overwash area. The rest of the beaches at Wells NERR, from Drakes Island Beach just west of Laudholm Beach to the jetties at the Webhannet, and then farther west to Wells and Moody beaches, are rimmed by dense residential development on the former dunefield. Drakes Island Beach and many stretches of Wells and Moody beaches are bordered by seawalls: at high tide there is no useable beach at all, as water inundates the entire sand surface.

Historical and Cultural Setting

Henry Boade settled on and farmed the highest point along the coast of the newly established town of Wells in 1642, enjoying a sweeping view of Wells Bay and ready-made pasture in the form of salt marshes. From these earliest days, the principal road in the territory of Maine ran through the property, along the hard sand beach to a ferry crossing at the Little River mouth. The route's importance is known today from the rebuke suffered by the town of Wells at the pen of the Massachusetts general court in 1658 for "exceedingly badd" condition of the road.

The farm was sold to the Symonds brothers in 1655, with the Boade family retaining a life estate with farming rights. The land was worked for twenty years before the houses were burned and abandoned during King Philip's war. It apparently lay fallow during this dangerous period, until it was sold again in 1717 to the Clark family. Nathanial Clark resettled the property and re-established the farm which would remain in his family for over a century and a half. He and his heirs grew the operation into the largest, most productive farm in town. Agriculture typically consisted of oxen, cows, horses, sheep, pigs, grains and hay. All of these early owners actively participated in town government as selectmen (Butler 2005).

In 1881, the Lord family bought the property. George Clement Lord, president of the Boston and Maine Railroad, had a new rail station built at the end of Laudholm Farm Road and enjoyed the property as a summer retreat for himself and his family. Agriculture activity expanded with the addition of registered Guernsey cows in 1892, later becoming an award-winning herd that produced high-value milk and butter. When burning shingles drifted onto the farm from a quarter mile away reducing two barns to ashes, a magnificent "James Way" barn was put up in their place, and this sturdy construction still greets visitors today as they pull into the parking lot. During the 1920's and 1930's, the farm hosted "field days" open to the public, with music, speakers and children's activities (Butler 2005).

The farm continued as a full commercial venture until 1925 when most of the herd was sold. During the Depression, the farm was opened to boarders who enjoyed hay rides and the nearby beaches. In 1968, the Maine Department of Conservation purchased 199 acres of meadow, woodland, marsh and beach, ensuring public access to at least a portion of the holdings which had remained essentially unchanged since its settlement over three centuries earlier. Two years later, hundreds of neighboring acres were folded into the Rachel Carson National Wildlife Refuge, ensuring additional conservation management.

When word spread through town that the farm and remaining lands were going to be sold and developed, members of the community organized to protect and conserve it. The Laudholm Trust was formed by the people of Wells and nearby communities to rally support for the farm. In 1984, the Trust and NOAA provided funding to purchase the farm, helping to establish the 1,600-acre Wells National Estuarine Sanctuary under the 1972 National Estuarine Sanctuary Program. Two years later, it was rededicated as the Wells National Estuarine Research Reserve, the fourteenth in the nation. The last private owners were granted a life estate within the Reserve borders, just as the first

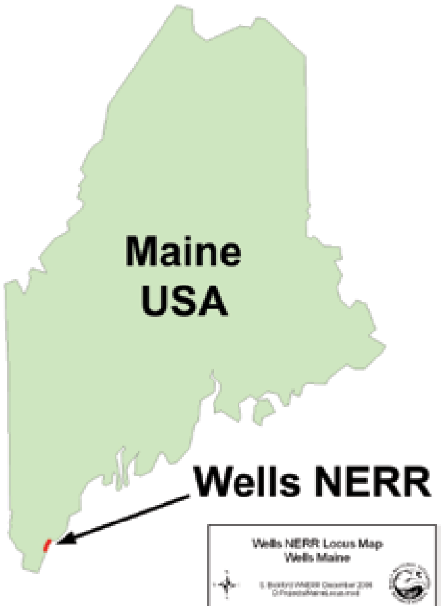


Figure 1-2: Location of Wells NERR.

owners had been three centuries earlier. The public now enjoys access to the farm and beach as so many family members and visitors have in the past (Butler 2005).

Wells NERR goes beyond providing public access to a historical site with miles of trails through undeveloped woods, fields and beaches (Fig. 1-1). Over four hundred volunteers give their time and often their valuable expertise to the Reserve. Citizens serve as naturalists who lead tours; research assistants who sample water, measure beach erosion, clean beaches, help with marsh restoration and shoreline surveys. Maintenance, library and administrative volunteers perform many essential tasks and form a strong grassroots link between the Reserve and the community that was so instrumental in creating it.

THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

The NERR system is a partnership between the National Oceanic and Atmospheric Administration (NOAA) and coastal states established in 1972 by the Coastal Zone Management Act of 1972, as amended. Currently, the network is comprised of 27 sites around the nation. Sites represent different biogeographic regions of the United States, and are protected for the purposes of long-term research, water quality monitoring, education and stewardship. Wells NERR is the northernmost Reserve on the East Coast. It is located in the southern Gulf of Maine province of the Acadia biogeographic region (Fig. 1-2). Wells NERR is one of two Reserves so located, the other being Great Bay NERR in New Hampshire. In contrast to Great Bay, which contains a large bay significantly inland from the ocean, Wells is comprised of two small watersheds on the open coast.

Reserves work with citizens, elected officials, non-profit organizations and other groups within their communities to address environmental issues such as non-point source pollution, habitat protection and restoration, and invasive species. Much of their stewardship efforts focus on land outside Reserve boundaries because upland activities there have a profound effect on estuarine water quality.

Wells NERR is a partnership between the National Oceanic and Atmospheric Administration and the State of Maine. Administrative oversight is vested in the Reserve Management Authority (RMA), established by the state in 1990 to support and promote the interests of Wells NERR. The RMA is composed of representatives having a property, management, program, or financial interest in the Reserve. RMA members represent the Maine Department of Conservation, the U.S. Fish and Wildlife Service, the Town of Wells, Laudholm Trust, the Maine State Planning Office and NOAA (Fig. 1-3). Wells NERR is unique among NERRs in that it does not receive dedicated state funding.

Wells NERR maintains collaborations with a range of local, state, federal and university partners to accomplish research, education and stewardship objectives. These include the Maine Departments of Inland Fisheries and Wildlife, Marine Resources, Environmental Protection; University of Southern Maine; University of New England; Natural Resources Conservation Service (U.S. Department of Agriculture); Gulf of Maine Council on the Marine Environment; Casco Bay Estuary Partnership; Southern Maine Regional Planning Commission; York County Audubon Society; and numerous land trusts and municipal conservation commissions. Wells NERR also has close ties to the Maine Coastal Program, which was instrumental in creating the Reserve. Another close

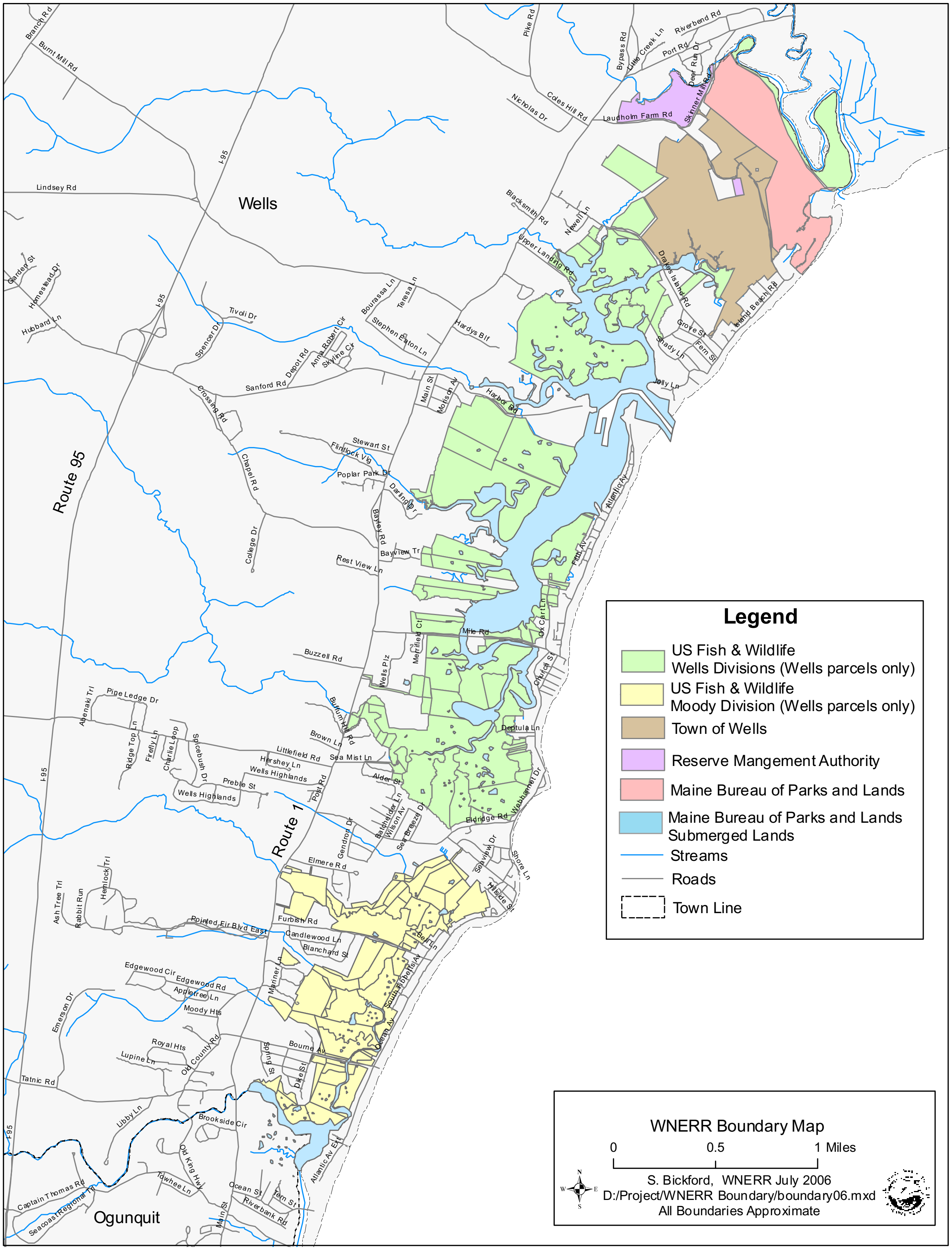


Figure 1-3: Wells NERR boundaries and land ownership. Map Sue Bickford.

partner in research and outreach is Maine Sea Grant, for which the Reserve provides an office on campus.

ECOLOGICAL SIGNIFICANCE AND DESIGNATIONS OF RESERVE

NOAA has identified 11 distinct biogeographic regions and 29 subregions in the U.S., each of which contains several types of estuarine ecosystems (15 C.F.R. Part 921, Appendix I and II). The Reserve System is designed to include sites representing all 29 biogeographic subregions, with additional sites representing different types of estuaries. The Reserve System currently represents 18 of those sub-regions (Fig. 1-4). The Wells Reserve is the only NERR in Maine and one of two NERRs located in the Acadian Biogeographic Region and the Southern Gulf of Maine Subregion.

MANAGEMENT PRIORITIES

The NERRs form a network of protected areas to promote informed management of the Nation's estuaries and coastal habitats. Federal regulations establish five specific goals for the system:

- ◊ Ensure a stable environment for research through long-term protection of National Estuarine Research Reserve resources;
- ◊ Address coastal management issues identified as significant through coordinated estuarine research within the System;
- ◊ Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;
- ◊ Promote Federal, state, public and private use of one or more Reserves within the System when such entities conduct estuarine research; and
- ◊ Conduct and coordinate estuarine research within the System, gathering and making available information necessary for improved understanding and management of estuarine areas.

Reserve System Research Funding Priorities

Federal regulations, 15 C.F.R. Part 921.50 (a), specify the purposes for which research funds are to be used:

- ◊ Support management-related research that will enhance scientific understanding of the Reserve ecosystem,
- ◊ Provide information needed by reserve managers and coastal ecosystem policy-makers, and
- ◊ Improve public awareness and understanding of estuarine ecosystems and estuarine management issues.

The reserve system is focusing on the following research areas to support the priorities above:

- ◊ Eutrophication, effects of non-point source pollution and / or nutrient dynamics;
- ◊ Habitat conservation and / or restoration;
- ◊ Biodiversity and / or the effects of invasive species;
- ◊ Mechanisms for sustaining resources within estuarine ecosystems; or
- ◊ Economic, sociological, and / or anthropological research applicable to estuarine ecosystem management

The Wells NERR approach to implementing the above national goals are embodied in its vision and mission statements.

Wells NERR Vision:

Healthy estuaries and coastal watersheds where coastal communities and ecosystems thrive.

Wells NERR Mission:

The Wells National Estuarine Research Reserve is dedicated to protecting and restoring coastal ecosystems of the Gulf of Maine through integrated research, stewardship, environmental learning, and community partnerships.

In support of the above, the following strategic goals have been developed for Wells NERR.

- ◊ Enhance the public's ability and willingness to appreciate and understand natural environments, make informed decisions, and take responsible actions to sustain coastal communities and ecosystems.
- ◊ Increase understanding of coastal ecosystems through Reserve science, and ensure the results of research are made available to address coastal management issues.

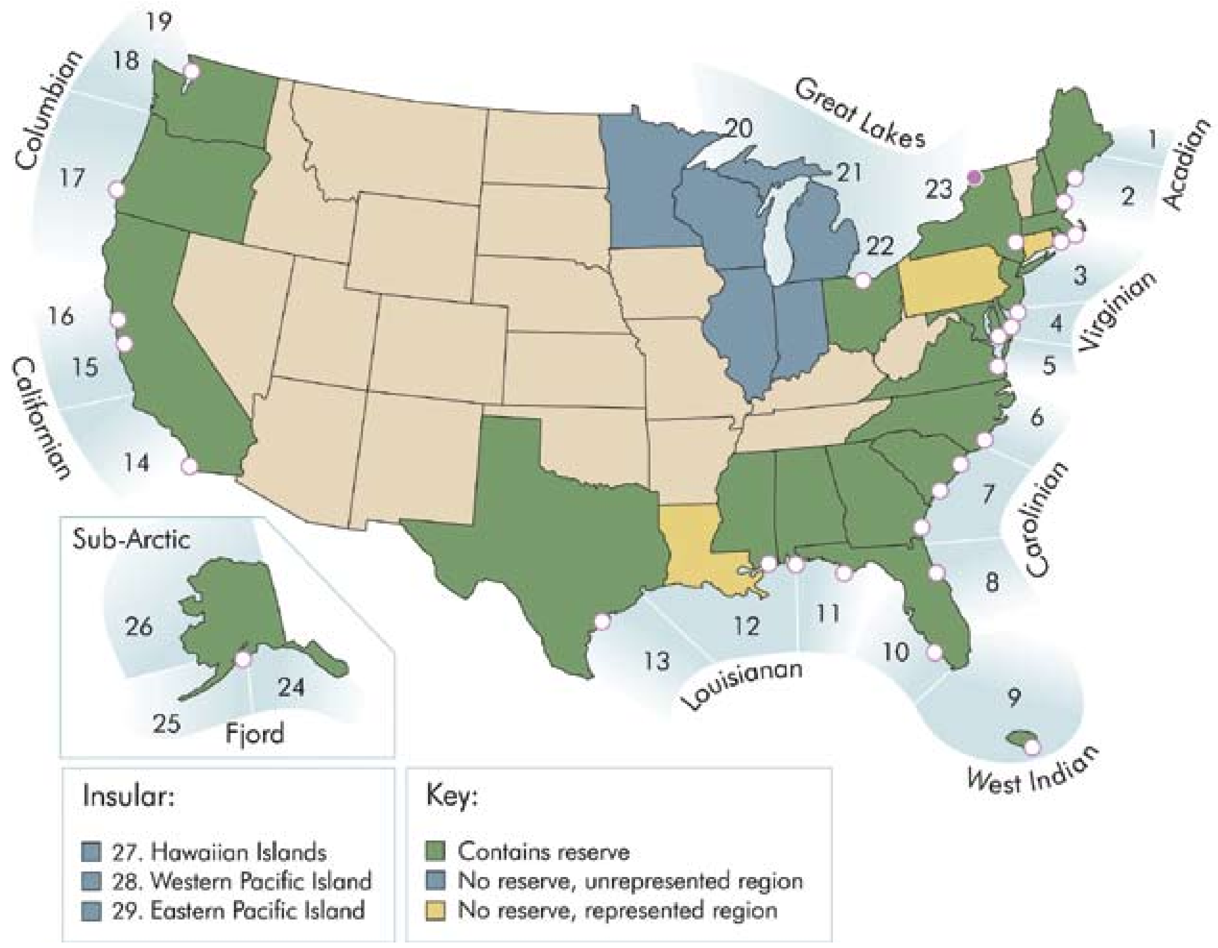


Figure 1-4: Biogeographic regions and locations of National Estuarine Research Reserves.

- ◊ Protect, manage, and restore the natural functions and diversity of coastal habitats for the benefit of communities and ecosystems.
- ◊ Serve as a model site and resource for exemplary coastal stewardship that fosters an understanding of the connections among land, water, and people.
- ◊ Foster a collaborative and collegial environment that values and recognizes personal contributions that enrich both the individual and the organization.
- ◊ Strengthen the organization's financial foundation to build capacity and enrich programs.

Strategic Objectives for Research Program:

- ◊ Objective 1: Investigate coastal food webs and habitats, their underlying physical and biological processes, and their response to natural changes and human activities.
- ◊ Objective 2: Provide visiting investigators and staff with opportunities to conduct independent or collaborative research at the Reserve and in the Gulf of Maine region.
- ◊ Objective 3: Promote the development and implementation of regionally coordinated ecological monitoring of coastal habitats, and continue to maintain and expand the System Wide Monitoring Program (SWMP).

RESERVE PROTECTION EFFORTS

Wells Reserve lands are owned by four distinct entities (acreage data from Wells NERR GIS): Maine Department of Conservation (146 acres); U.S. Fish and Wildlife Service/Rachel Carson National Wildlife Refuge (1,428 acres); Town of Wells (240 acres); and Reserve Management Authority (40 acres). Wells NERR also includes 386 acres of submerged lands owned by the Department of Conservation. Submerged lands within the Wells Harbor Federal Navigational Channel are excluded from the Wells Reserve (Fig. 1-3).

Management of state, town, and RMA-owned lands is carried out by the Reserve Management Authority using recommendations made by the Stewardship Advisory Committee. Federal lands are managed by the U.S. Fish and Wildlife Service.

The Wells Reserve has created four management zones: Public and Administrative, Active Management, Conservation, and Protected. These management zones are used to control the types and levels of access and activities at the Reserve. They allow research, education, resource management, and public enjoyment while providing adequate protection to sensitive areas.

An extensive trail system allows visitor visual access to the full range of habitats that make up the Reserve. These trails provide opportunities to view and learn about wildlife and their habitats even when visitors are near or within habitats receiving protection or intensive management.

Public and Administrative Zone

This zone includes a campus of buildings, pathways, parking lots, and other infrastructure to accommodate employees, visiting researchers and educators, and the public. This area is the most intensively used on the Reserve property and supports large and small events and activities. It includes the Visitor Center, barn, auditorium, Maine Coastal Ecology Center, parking area, entrance road, and the landscaped grounds that immediately surround these facilities. A second area within the public and administrative zone contains the buildings and immediate surroundings of the Alheim Property, which includes housing for visiting researchers. Stewardship in the public and administrative zone relates primarily to building upkeep and grounds maintenance. Management activities within the zone include mowing and snow removal.

Active Management Zone

This zone consists of 90 acres of fields and shrublands. These include the grounds surrounding the Visitor Center and six fields that have a long agricultural history. Shrubs along the perimeter of these fields form an edge habitat valuable to wildlife. Stewardship within this zone is guided by the Reserve's open-field management plan. Management activities within the zone include prescribed burns, mowing, brush hogging, and periodic tree cutting. These activities are timed to avoid adverse impacts on wildlife. The Reserve's open-field management plan sets these goals for managing fields and shrublands:

- ◊ Maintain the fields for their visual appeal, historical value, and ecological significance;
- ◊ Provide habitat for a range of grassland-nesting birds and other wildlife that use open fields for feeding, nesting, roosting, and hunting;
- ◊ Control and curtail the spread of non-native species.
- ◊ Encourage the growth of native grasses and rare plants that need full sunlight to thrive;
- ◊ Regenerate desirable shrub species like alders to provide edge habitats for birds and mammals;
- ◊ Provide educational opportunities for the public on topics of natural succession, habitat change, and land-use history.

Conservation Zone

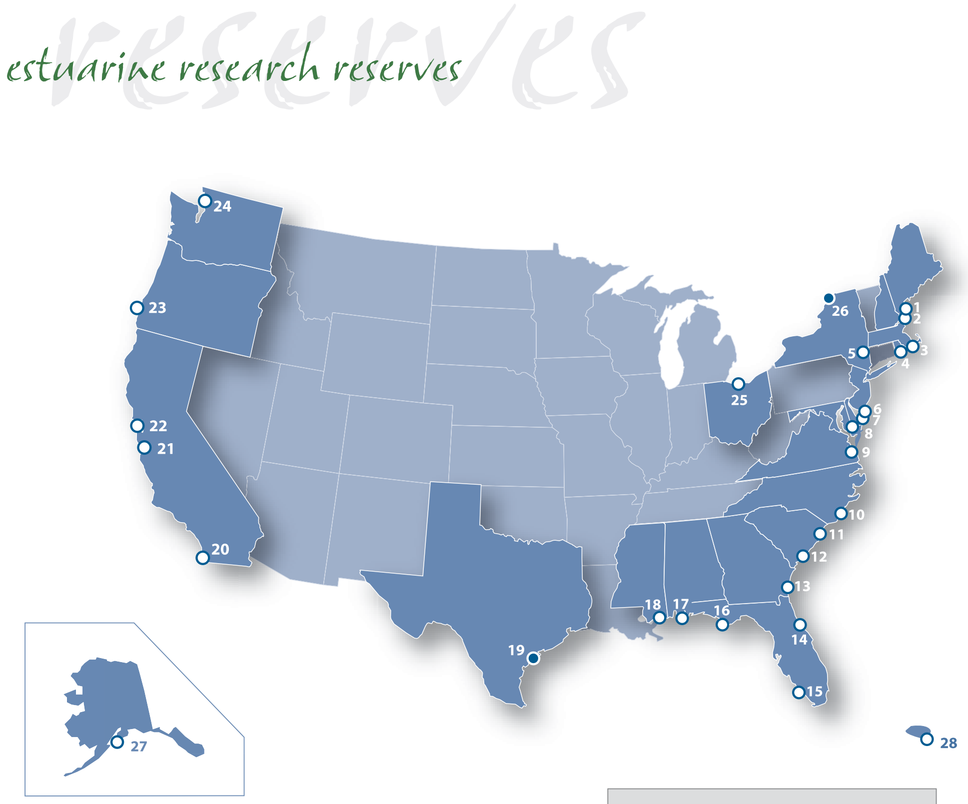
This zone comprises most of the Reserve's forests and shrublands. Stewardship and resource management within this zone is intended to maintain relatively undisturbed, natural habitats. It focuses on minimizing disturbance to plants and wildlife, while ensuring public safety. Management activities within the zone include tree and shrub cutting and trail maintenance.

Protected Zone

This zone includes areas deemed in need of greatest protection because they support sensitive species (state or federal rare, threatened, or endangered species) or sensitive habitats. Sensitive habitats within the Reserve include dune systems, salt marshes, freshwater wetlands (including streams, vernal pools, forested wetlands, and wet meadows), and tidal waterways. Stewardship within this zone requires that areas are closed except by permit for specific interpretive education programs, research projects, or stewardship and management activities.

REFERENCES

Butler, Joyce. 2005. Laudholm: the history of a celebrated Maine saltwater farm. Wells National Estuarine Research Reserve and Laudholm Trust. Wells, Maine. 28 pp.



1. Wells Reserve, Maine
2. Great Bay Reserve, New Hampshire
3. Waquoit Bay Reserve, Massachusetts
4. Narragansett Bay Reserve, Rhode Island
5. Hudson River Reserve, New York
6. Jacques Cousteau Reserve, New Jersey
7. Delaware Reserve
8. Chesapeake Bay Reserve, Maryland
9. Chesapeake Bay Reserve, Virginia
10. North Carolina Reserve
11. North Inlet-Winyah Bay Reserve, South Carolina
12. ACE Basin Reserve, South Carolina
13. Sapelo Island, Georgia
14. Guana Tolomato Matanzas Reserve, Florida
15. Rookery Bay Reserve, Florida
16. Apalachicola Reserve, Florida
17. Weeks Bay Reserve, Alabama
18. Grand Bay Reserve, Mississippi
19. Proposed Reserve—Texas
20. Tijuana River Reserve, California
21. Elkhorn Slough Reserve, California
22. San Francisco Bay, California
23. South Slough Reserve, Oregon
24. Padilla Bay Reserve, Washington
25. Old Woman Creek, Ohio
26. Proposed Reserve—St. Lawrence River
27. Kachemak Bay Reserve, Alaska
28. Jobos Bay Reserve, Puerto Rico

○ designated ● proposed

Fig. 1-5: The National Estuarine Research Reserve System.

II. Environmental Setting

Geomorphology

Climate and Weather

Hydrogeography

Land Use

Water Quality

CHAPTER 2

Geomorphology

BRITT ARGOW

Barrier beaches are found along 18% of North America's coasts, mostly along the Atlantic and Gulf seaboards. These barrier islands and spits create a quiet, sheltered environment in which unique and diverse lagoon, marsh, and tidal flats develop, known collectively as the back-barrier. About 100 km of Maine's roughly 5,600 km coast is protected by barriers (Kelley 1987, Duffy *et al.* 1989). Relatively little research has focused on the ecological, sedimentary and physical processes that shape this coastal environment relative to its southern counterparts. Wells NERR includes perhaps the largest and best studied estuarine and marsh system in Maine, and is an important example of a northern back-barrier system.

Wells NERR is located at 43°19'N and 70°34'W in the Wells Embayment on the Gulf of Maine. The Wells Embayment is defined by its arcuate coastline, and lies offshore between the Kennebunk River and the Ogunquit River inlets. The Embayment has an irregular seafloor dominated by bedrock outcrop and relict deposits of glacial sediments from the last major North American ice sheet. Geophysical technology allows us to visualize the layers below the surface and glimpse the sediments of the seafloor (Kelley *et al.* 1988, Fig. 2-1, Fig. 2-2, Fig. 14-2). Sand is only a thin cover on the nearshore in most places (Miller 1998). The dominant sources of sand for the present coast include reworking of this narrow and thin wedge during sea-level rise, and new sediment introduced from glacial deposits at headlands.

The coast of Maine has been and continues to be shaped by the forces of wind, waves and tides. Maine experiences semidiurnal tides (two high tides and two low tides daily) along its 5,600 km coastline (Dickson 2003). The mean tidal range (the vertical difference between mean high tide and mean low tide) at Wells Inlet is 2.7 m, increasing to 2.9 m around full and new moons each month (Ch. 15, Fig. 15-4). Winds are seasonal, coming from the north and northeast during the colder months and primarily from the south and southwest during the summer (Ch. 3, Fig. 3-4, Fig. 3-5). Waves generated by these winds vary seasonally in their direction of approach to the shoreline (Byrne and Ziegler 1997), and also in their height. The largest waves, which have the highest energy, approach from the northeast and are associated with Northeasters and winter storms. These waves can be 7 meters in height while offshore on the western continental shelf of the Gulf of Maine (GoMOOS), and will increase in height and steepness as they approach the shore. These waves are often responsible for massive erosion during a single storm event, and are a dramatic reminder of the power of the sea. During most of the year, however, wave approach into the Wells Embayment is from the south and

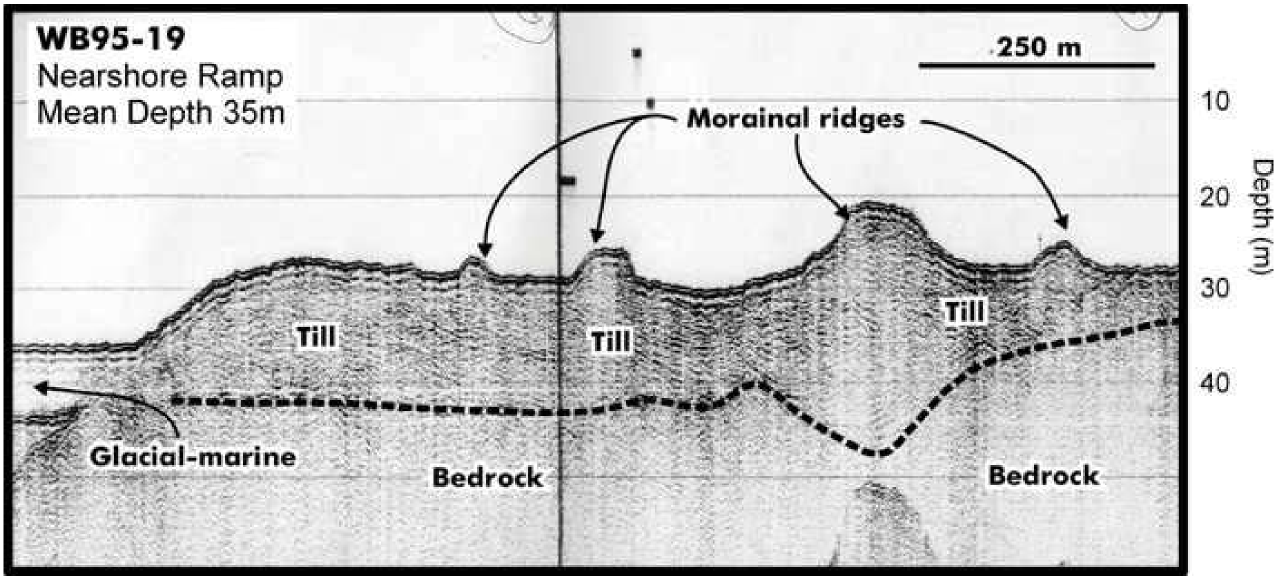


Figure 2-1: Seismic reflection profile. Glacial deposition left morainal ridges on the inner shelf as the ice retrated. Subsequent reworking produced a seafloor composed of sand and gravel with some boulders. The horizontal dotted line traces the border between glacial till and the bedrock below. Source Maine Geological Survey.

southeast, and these calm-weather waves are smaller and less energetic (GoMOOS), yet due to their steady, constant action, they dominate coastal sedimentation processes on the open coast of the Wells NERR barrier and headlands.

Back-barrier environments generally experience reduced wave, storm and wind conditions relative to open coastlines. The resulting lower-energy environment becomes a sediment sink for sands and muds carried into the system via the ocean inlet or from rivers and streams draining the upland. The evolution of this coastal system will be discussed in Chapter 14; here we focus on the physical characteristics and processes of the dominant ecosystems and environments of the back-barrier and surrounding uplands.

BARRIER BEACHES

The barrier system at Wells NERR comprises two beaches: Wells Beach, south of Wells Inlet, and Drake's Island Beach and Laudholm Beach (a single system) to the north. Wells Beach is a barrier spit, anchored on the till and bedrock outcrops of Moody Point. The Drakes Island / Laudholm Beach, located between Wells Inlet and Little River Inlet, is a barrier island anchored on till. The barrier and inlet complex of Wells NERR is near the northern end of a semi-continuous chain of barrier islands and spits stretching southwest along the coast of Maine, New Hampshire, and Massachusetts to Cape Ann.

The Wells NERR barrier system itself is a long, low coastal feature. Stretching a total of 4.7 km in a gently curving arc from its anchor points on Moody Point to the till that forms Drakes Island (Fig. 2-3), the barrier island stands only 2 - 4 m above mean sea level. Wells Beach barrier is heavily developed, and large sections of the beach have been stabilized by sea walls or revetments. Stabilization protects property in the short term, but alters the natural evolution of the barrier complex and prevents the island from migrating landward in a regime of rising sea level by reducing overwash processes. The three or more rows of houses effectively stop the action of winds moving sediment from the beach into a dune system and onto the back-barrier (Jacobson 1988). The development of Wells Beach has resulted in several changes to the shoreface, discussed in more detail in Chapter 14.

The beach runs 3.5 km north from Moody Point to Wells Inlet (Wells Beach), and 2.2 km from Wells inlet to the Little River Inlet (Laudholm Beach). Both beaches narrow to the south. Wells Beach is ≈ 250 meters wide at low tide at the inlet, and gradually becomes narrower

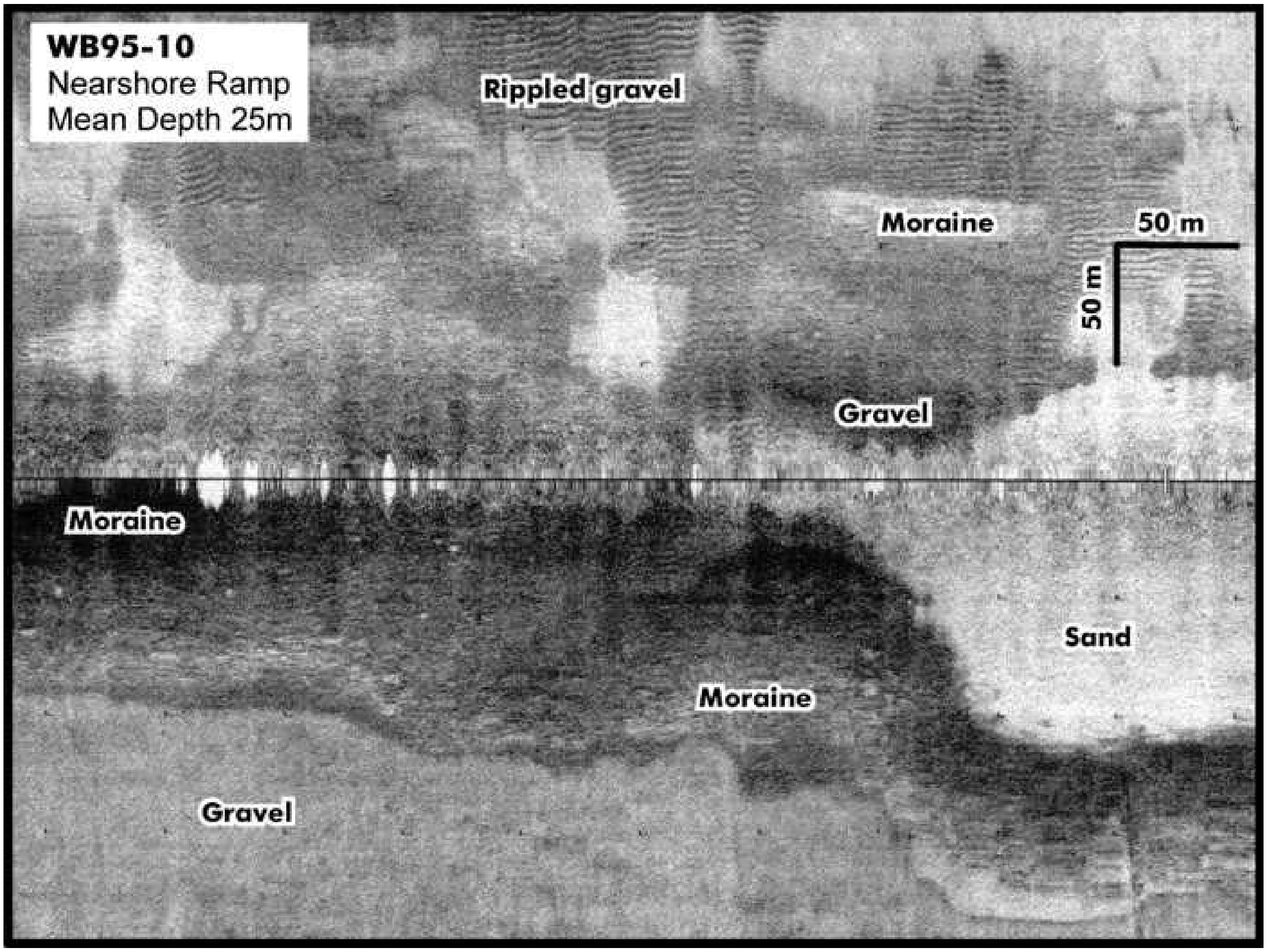


Figure 2-2: Side-scan sonar image of the seafloor, looking down on a 5 – 10 m high moraine in the Wells Embayment. Nearby sand and gravel deposits were once part of the moraine but have been removed by erosion. This technique is used in combination with seismic reflection profiles and bottom sampling to determine substrate type. Source Maine Geological Survey.

until it tapers and disappears at Moody Point. Laudholm Beach is more consistent in width and the narrowing is more subtle, widening again at the northern jetty. Low-tide beach width ranges from 140-200 meters over its length.

The variation of beach width is a function of the dominant direction of wave approach from the southeast and the resulting transport of sediment in a northerly direction along the shoreface. These waves also move sediment onshore, building up and widening the beach over the summer months. The north-south shoreline asymmetry is milder than one might expect, however, because of the influence of Northeaster storms which move large quantities of sediment in a southerly direction along the beach, as well as offshore. Currently there is a near balance of northerly and southerly transport in the long term (Belknap *et al.* 1995), best demonstrated by the symmetry of the deposits that have built up on both sides of the jetties at Wells Inlet (Timson and Kale 1976).

Major winter storms are largely responsible for the seasonal variation in beach width observed at the barrier beach fronting Wells NERR, as the large waves associated with winter storms have so much energy that they do not expend it all crashing on the beach, and therefore carry sediment offshore as well as up the beach face. During especially large storms, overwash may occur in lower (or less-protected) sections of the barrier spit system. In a natural setting this same process moves sediment from the beach onto the barrier island, raising the elevation of the island and helping it to maintain its position with rising sea level. In lower and thinner sections of a barrier, or on barriers that have been stabilized, overwash will deposit sediment in the back-barrier environment when it occurs.

The barrier itself is made up of layers of sand and gravel. These sediments are re-worked deposits first brought to the area by glacial processes during the last major glaciation of North America (Ch. 14). The barrier is anchored in its present position along the coast by till and bedrock outcrops (Fig. 2-3).

Soils on the barrier are derived from the sands that dominate the stratigraphy of this feature, and are characterized as thin, sandy loam.

SALT MARSHES

The extensive salt marshes of the Webhannet River and Little River marshes are among the largest in the state. They form a broad, flat, vegetated platform deeply incised by tidal channels and creeks (greens in Figs. 2-3 and 2-7). These intertidal environments cover approximately 526 ha, and are the most obvious recognizable ecosystem in the Reserve for many visitors. They formed over the last 4,000 years or so during a time of relatively slow sea-level rise (approximately 10 centimeters per century), but today face a much higher rate of sea-level rise (about 25 centimeters in the last century). Rates of sea-level rise are expected to keep accelerating, resulting in the inundation and loss of these salt marshes if they are not able to maintain their position relative to rising sea level.

Low marsh colonizing sandy tidal flat in Webhannet Estuary. An established low marsh ramp is visible to the west (right), and the cliffed leading edge of the high marsh platform can be observed above the ramp. Photo Britt Argow.

There are two major classifications of salt marsh ecosystems found in Wells NERR. Low marsh systems form between mean tide level and mean high-water (generally from 0.8 to 1.3 meters above sea level at Wells NERR), and are commonly defined in the field by their vegetation. They appear to be a near-monoculture, comprised almost exclusively of the halophyte (salt-tolerant) grass species Smooth cordgrass (*Spartina alterniflora*). At Wells NERR, low marsh ecosystems are restricted to narrow ribbons along tidal creeks and to slumped ramps along the main tidal channels. The high marsh, in contrast, inhabits broad, fairly level fields, and makes up the majority of the marsh system in the Webhannet estuary (Fig. 2-3). High marsh is formed at elevations around and above mean high tide level (1.39 meters above mean sea level at Wells Inlet), up to the upland margin ecosystem that begins at the limit of highest spring tidal inundation (around 2 m above mean sea level). The high marsh community is fairly diverse, but at Wells is dominated by salt marsh hay (*Spartina patens*).

Salt marshes at Wells NERR, like most New England marshes, formed in a regime of slow, steady sea-level rise. But what will happen if rates of sea-level rise increase, as has been predicted (Church *et al*. 2001)? Coastal wetlands respond to changes in local sea level by migrating seaward as sea level falls, and by accreting vertically and migrating landward (where local topography allows) as sea level rises. Vertical accretion is the result of both mineral sediment influx and the production of organic matter, and is therefore also dependent on suspended sediment concentrations, nutrient abundance, and storm frequency and intensity (Leonard, 1997; Leonard and Luther, 1995; Leonard *et al*. 1995; Reed 2002). The hypsometry of the marsh, type and abundance of vegetation and resulting patterns of hydrologic flow can also impact marsh accretion (Boon and Byrne, 1981; Leonard and Luther, 1995). Past studies indicate that there may be a limit to annual accretion rates in salt marshes, making this environment extremely vulnerable to acceleration of rising sea level (e.g. Redfield 1972; Bricker-Urso *et* *al.* 1989; Reed 1995; Callaway *et al.* 1997; Reed 2002; Rybczyk and Cahoon 2002).

Marshes throughout the world have been investigated to quantify rates of vertical accretion[1]. Methods used include direct measurement of vertical accretion on the surface of the marsh, measurements of sedimentation rates using known marker horizons (Fig. 2-4), and historical measurements calculated by linear regression from radiometric dates. The total range of accretion rates reported is 0 -14 millimeters per year, with a mean of 5.0 millimeters per year (FitzGerald *et al.* 2006). If the upper end of this range reflects the maximum rate at which coastal wetlands can vertically accrete, then all marshes should potentially be able to keep up the average projections of sea-level rise rates. A closer look at the data, however, reveals that low marsh can accrete much more rapidly than can high marsh (a mean of 6.1 mm yr^{-1} versus 2.6 mm yr^{-1}; FitzGerald *et al.* 2006, Fig. 2-5). This difference reflects the larger contribution of inorganic sediment to the low marsh as a function of more frequent tidal inundation, as well as the greater bioproductivity of low marsh plants relative to high marsh plants (Bagwell and Lovell 2000; Foote and Reynolds 1997; Gabrey and Afton 2001). High marshes may be more vulnerable to accelerated sea-level rise, as they accrete more slowly, with a higher proportion of organic matter, being distant from sources of inorganic sediment. Many high marshes may not be able to keep up with the projected acceleration in the rate of sea-level rise. In back-barrier environments, this may trigger dramatic coastal evolution (Ch. 14). The back-barrier marshes of New England form a unique ecosystem that is currently

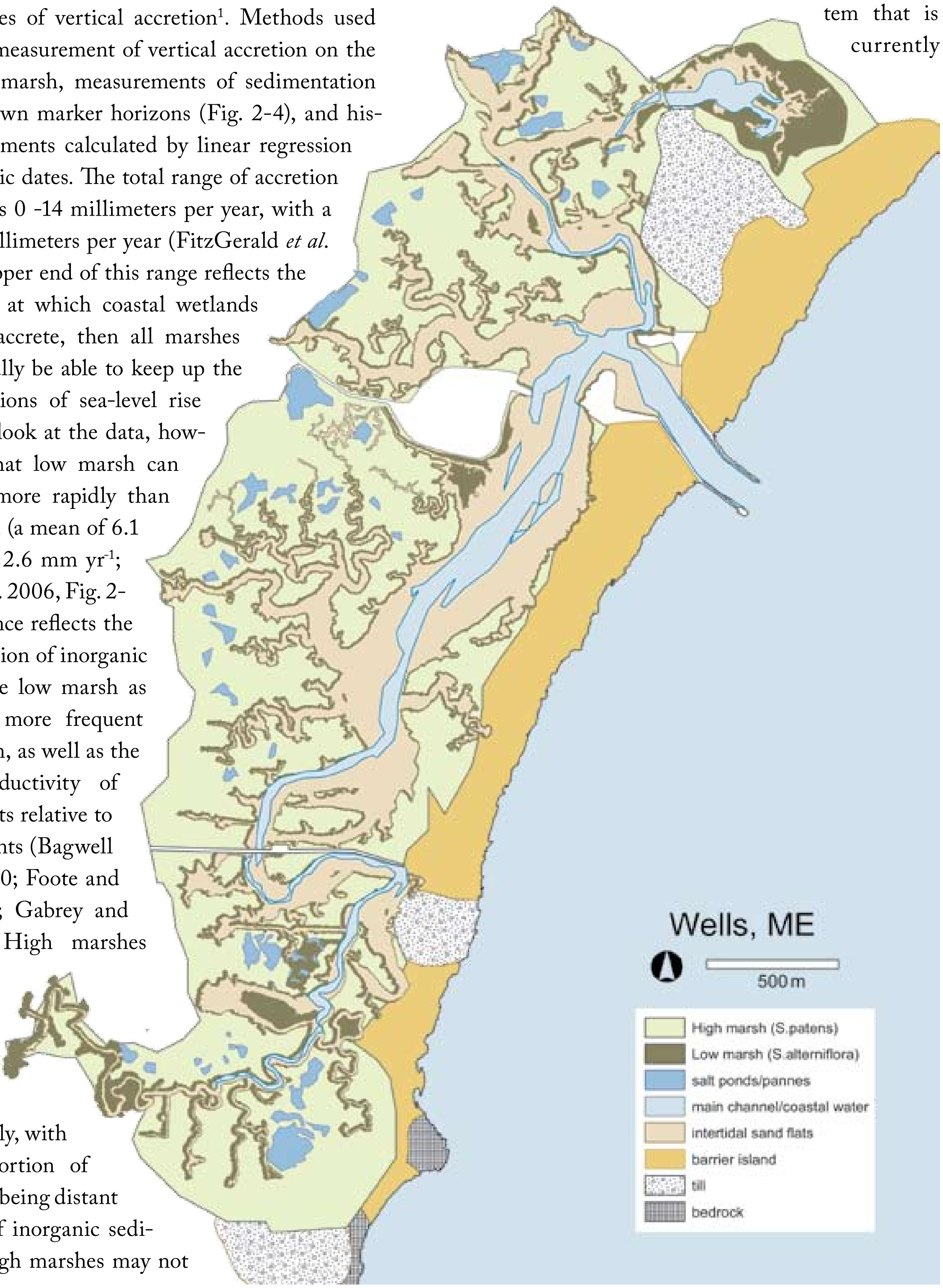


Figure 2-3: Geomorphic provinces of the back-barrier and barrier island complex at Wells NERR (Argow 2007).

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[1] For a list of world-wide accretion research locations and scientists, see the USGS Patuxent Wildlife Research Center's directory, available at http://www.pwrc.usgs.gov/set/ (Acessed 13 November 2006).

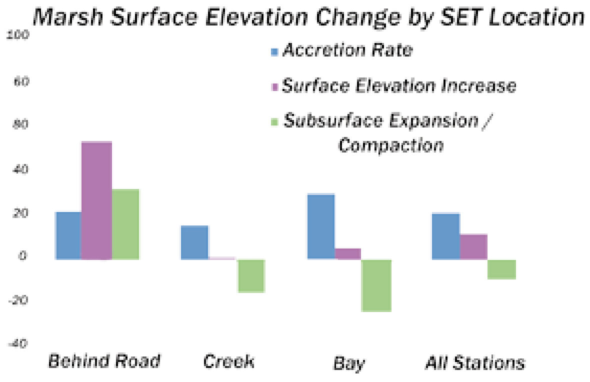


Figure 2-4: SET (sediment elevation table) data from the Webhannet marsh. Source David Burdick, University of New Hampshire.

threatened by projected increases in sea level (Kelley *et al.* 1988, Kennish 2001, Donnelly and Bertness 2001).

In Wells NERR there is a distinct change in slope between the flat lowlands along the coast and the relatively steep uplands, and this landscape is characteristic of much of New England's coastal zone. Because of this topography, New England marshes may not be able to maintain their current area by landward migration as sea-level rises; these marshes must accrete at a rate comparable to rising sea level in order to survive.

Current research at Wells NERR shows that the Webhannet marshes are accreting at an annual rate comparable to local rates of rising sea level (Gehrels 1994, 1999, 2000; Gehrels *et al.* 1996, 2002; Goodman *et al.* 2006). However, changes in vegetation on the high marsh may be an early warning of a marsh in distress. Through processes associated with formation of pannes (ephemeral waterlogged areas) and pools (small, persistently water-filled depressions), it may be possible to evaluate whether or not Maine's marshes (and nearby areas) may be profoundly changing or eroding. These changes in pannes and pools may be harbingers of overall marsh health, help identify stresses on marshes including anthropogenic influences, and help predict future responses to climate and sea-level change (Belknap and Kelley 2006; Wilson 2006). See chapter 18 for details on emergent vegetation monitoring at Wells NERR.

The average rate of high marsh accretion is 2.6 mm yr^{-1}, which is comparable to modern rates of sea-level rise in New England (Kelley *et al.* 1988, van de Plassche 1998). This would seem to indicate that these marshes are at present stable coastal systems, but that they may not be able to keep up with accelerated sea-level rise. However,

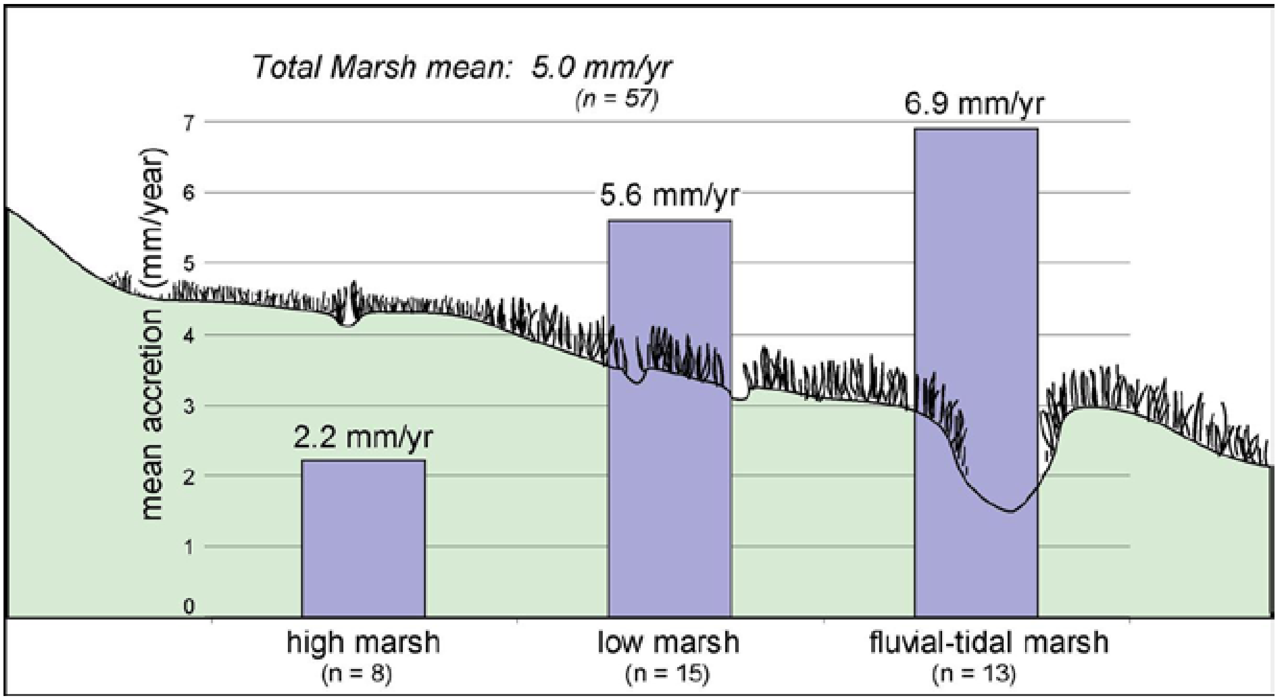


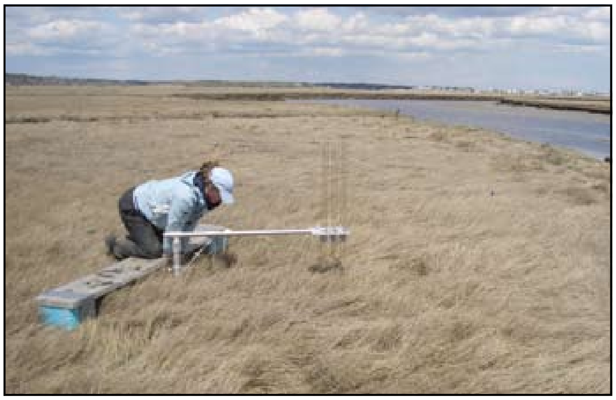
Figure 2-5: Summary of literature values for sediment accretion by marsh zone (Argow 2007).

scientists are still working to untangle the complex biological, sedimentological, and hydrodynamic factors that control the elevation of the marsh (Fig. 2-4). Climate and morphological differences may be the key, as these may turn out to be critical controls on vertical accretion.

Morphologically, northern marshes are dominated by high (supratidal) marsh, while southern marshes are primarily low (intertidal) marsh. These factors may impact vertical accretion by affecting sediment influx and bioproductivity, and will control the pattern and threshold of flooding should the marsh be unable to keep up with rates of rising sea level (Fig. 2-6) (Argow and FitzGerald, 2006). In addition, Northern marshes experience colder average temperatures, more days with temperatures below freezing, and longer duration and thickness of snow and ice cover than do their southern counterparts.

Relatively little research has focused on marsh winter processes. Previous work indicates that ice rafting may have a measurable impact on vertical accretion in northern marshes (e.g. Dionne 1989, Wood *et al.* 1989, Kelley *et al.* 1995, Ollerhead *et al.* 1999, Goodman *et al.* 2006). Work has been limited by the difficulty of quantifying ice rafting and the total volume of sediment redistributed across the marsh surface, but careful field study can yield useful approximations. Ongoing research at Wells NERR indicates that a measurable and significant volume of sediment is indeed deposited on the marsh surface via ice rafting. This sediment influx accounts for as much as 50% of the inorganic material contributed to peat development each year, and may be critical to vertical accretion on the marsh surface. Raising the surface elevation of the marsh is critical if the marsh is to survive in a regime of rising sea level (Argow and FitzGerald 2006).

Wetlands loss is a serious problem facing the global community (Gornitz 1995, Church *et al.* 2001, Kennish 2001, Adam 2002). Coastal wetlands are among the most productive ecosystems on earth, serving as nursery grounds for many marine species and supplying a substantial amount of detritus and living biomass to the waters offshore, supporting secondary oceanic productivity. Marshes are sinks for pollutants, and filter surface waters before they reach the oceans. Wetlands are also important buffer zones, absorbing storm energies and storing flood waters. The loss of this protection presents an unmistakable hazard to inland areas. More than half of the world's population lives within 50 km of the coast (Titus 1990), and this environment is already under intense pressure from anthropogenic effects. If accelerating rates of sea-level rise cause marshes to be inundated, the conversion of marsh to open water in the back-barrier environment could initiate a cycle leading ultimately to coastal transgression, ie. inland movement of the coast. Today, evidence suggests the rate of sea-level rise is increasing, threatening the survival of coastal wetlands.



Preparing the SET (sediment elevation table) for measurement of change in the elevation of the marsh surface on the high marsh north of Mile Road, early spring, 2005. Photo Britt Argow.

Tidal Flats

Tidal flats make up a relatively small percentage of the total intertidal area of Wells NERR. This sedimentary environment is characterized by gentle slopes and sandy or muddy substrate, and is home to a diverse population of benthos. Tidal flats may form at elevations from spring low tide (1.45 m below sea level) to spring high water (1.45 m above sea level), depending on the amount of energy along the shore from waves and tidal currents.

The sand and mud that make up a tidal flat are brought to the estuary from two sources: rivers and streams, or the ocean via the tidal inlet. Muds more commonly are sourced in the uplands; a greater percentage of sand is derived from the nearshore and littoral regime and is moved into the inlet by waves and tidal currents. Tidal flats build up in areas of relatively low energy and little wave action and slower tidal currents in the estuarine environment. If the energy of the environment is too great, then sand and mud will not be able to settle and form a tidal flat. In environments with moderate to low energy, sand flats may form as sand can settle out while clays will still be suspended in the water column and will wash back out with the tide; in low-energy conditions mud will be deposited and mud flats will form.

Estuarine processes act to concentrate fine cohesive sediments (clays) as well, enhancing the deposition of muddy tidal flats. Flocculation is a process in which tiny particles of clay in the water column are attracted to one another and aggregate to form larger particles, which can then settle to the bottom during slack high water when tidal current velocities are low. Tidal pumping occurs when the incoming tidal waves shoals on the rising bottom of the estuary as it moves from the inlet towards the estuary's head. This process moves sediment-laden water into the estuary more effectively than back out to sea, due to the difference in velocity and the relative channelization of flood and ebb currents. Finally, estuarine circulation itself has a tendency to move fine sediment up into the estuary, as relatively dense saline sea water moves into the estuary along the bottom, while fresher lighter water moves outward at the top of the water column. Hence, as sediments drift down through the water column, they are likely to be moved farther into the estuary by density-driven currents before they settle on the bottom. This explains why the tidal flats and channels of the estuary get progressively muddier towards the head of the estuary, and are sandy near the inlet.

In the upper intertidal zone above mean sea level, tidal flats may be colonized by *Spartina* grasses and converted to tidal wetlands. This process has reduced the total area of tidal flat at Wells NERR significantly over the past 4,000 years (Fig. 2-6).

TIDAL CHANNELS

Tidal channels incise the salt marshes and tidal flats of the Wells NERR estuarine systems. This system of creeks and larger channels drains the intertidal region during ebb tides. The tidal network is also the conduit for rising flood tidal waters, until the water level reaches the height of the banks and floods the marsh surface, after which tidal flow in the back-barrier is driven by estuary-wide circulation patterns.

Tide channel development on mud and sand flats is primarily controlled by ebb drainage patterns in the major channels, because the current velocities are greater during

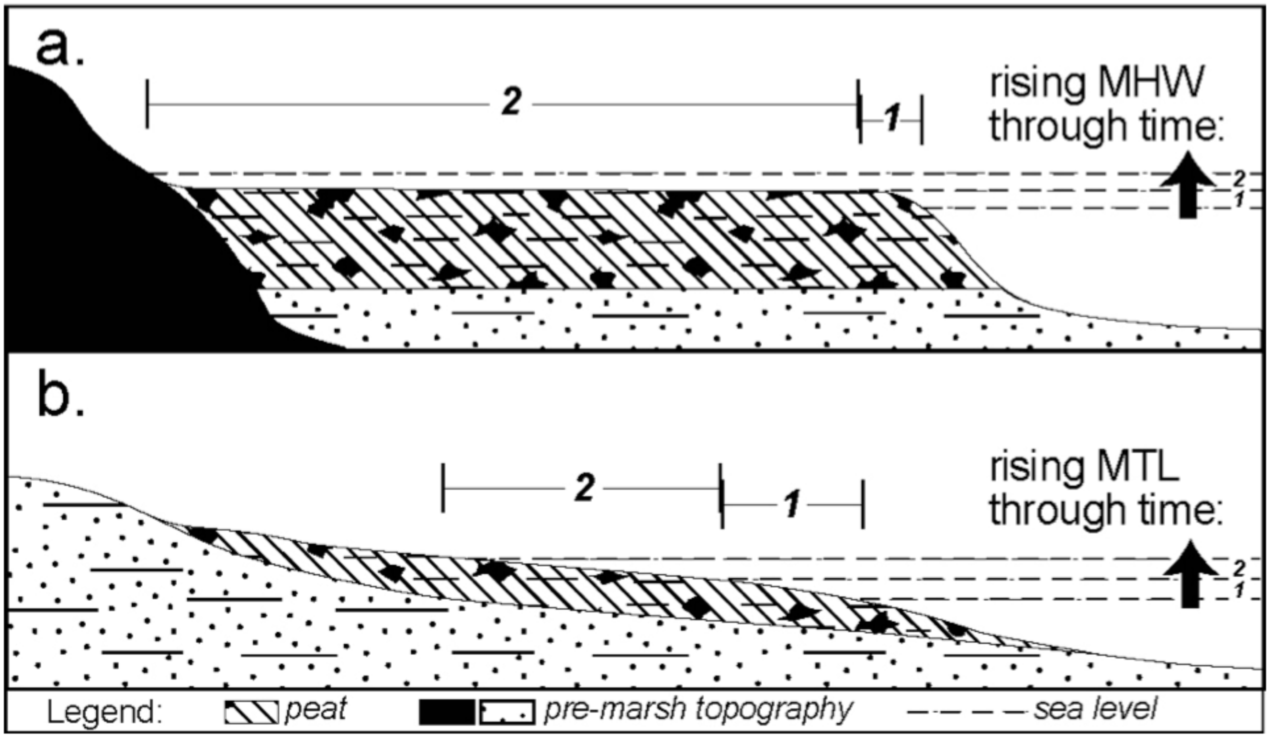


Figure 2-6: Salt marsh cross-sections: a) Platform marsh morphology, b) Ramped marsh morphology (Argow 2007; similar figure appears in Argow and Fitzgerald 2006).

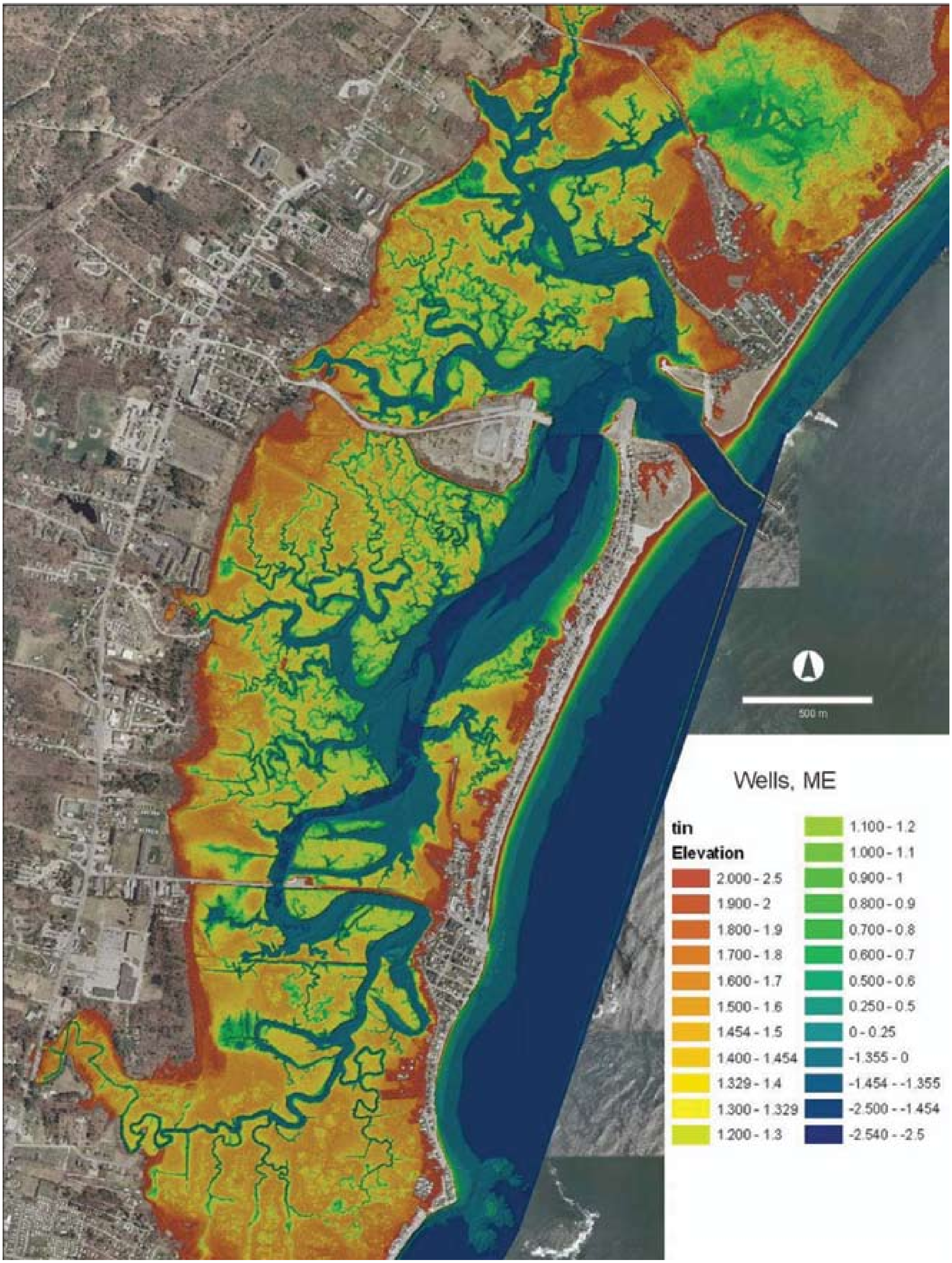


Figure 2-7: Triangulated Irregular Network image of Webhannet marsh elevations made with NOAA LIDAR data (Argow 2007).

ebb tide in tidal channels, although flood tidal currents do affect the morphology of the drainage network as well. Tidal channels may meander across sand and mud flats in response to changes in tidal current flow and sedimentation rates. After tidal flats become colonized by vegetation, however, the tidal creeks become more stable and tend to migrate much more slowly through time. Sediment in the tidal creeks and channels of the Webhannet estuary is transported into the back-barrier through the tidal inlet from the Gulf of Maine, and probably represents re-suspended coastal shelf deposits that are in turn re-worked glacial sediments.

Sand (and during storms, gravel) tends to shift back and forth with the tides in sand ripples or waves that resemble low underwater sand dunes, pushed along the channel bed by tidal currents. Smaller particles are moved as suspended sediment with the water. The net movement of sediment, both as suspended flow and as bedload, is towards the estuary head, gradually filling the estuary with sediment over hundreds or thousands of years. This infilling is caused by a phenomena known as 'tidal asymmetry.'

Highest flood-tide velocities occur 3—4 hours after low tide. As the salty, dense ocean water moves into the tidal channels, the fastest velocities occur at the bottom of the water column, scouring sediments from the channel bed and re-suspending fine-grained material, which is then carried farther into the marsh with the rising tide. The imbalance in ebb and flood velocities results in a longer period of low-velocity "slack water" around high tide, and is a function of the time lag between high and low tide at the head of the estuary versus at the inlet. As the flood current begins to propagate through the inlet and back into the far reaches of the estuary through tidal channels, water from the last high tide is still draining off the vegetated marsh surface, and slows the progress of the rising tide.

During the hours of low-velocity currents surrounding high tide, fine sediment can be deposited. The water also mixes with the freshwater influx from rivers, overland flow or groundwater discharge, and becomes less dense. As it begins to drain back out of the marsh system, the highest-velocity currents are found at the top of the water column, and flow rapidly becomes concentrated in tidal creeks. It takes between 4—6 hours for maximum ebb-tidal velocities to be reached, and by this time the water level has lowered so that most intertidal areas are already exposed. That means that only the deepest channels are scoured by the outgoing tide, despite the higher velocities and greater net flow (due to freshwater influx). This is why the Little River and Webhannet marsh surfaces are flood-dominated and are an inorganic sediment sink, while larger tidal channels and the inlets are ebb-dominated. Lighter organic matter particles (detritus), however, can be easily moved by even the low-velocity currents of high tide, so the marshes experience net export of organic matter to the adjacent coastal area even though they import sediment.

Figure 2-8: Freshwater streams feed into Wells NERR estuaries. Drawing Robert Shetterly.

RIVERS AND STREAMS

Each estuary at Wells NERR is fed by freshwater rivers and streams. The Webhannet River enters the Webhannet estuary towards the south end of the Reserve, and the Blacksmith and Depot Brooks enter the estuary north and south of Wells Inlet, respectively. The Little River meanders to the sea from the northwest and ends in the Little River estuary and inlet (rivers and streams are generally the darkest blue channels on Fig. 2-7).

The Little River is formed from the confluence of the Merriland River and Branch Brook. The drainage area of the Little River estuary is the larger of the two, at 30.4 mi2 (84 km^2), despite the fact that it is a much smaller estuary and has a smaller tidal inlet with the Atlantic Ocean (27 meters wide). The Webhannet estuary is fed by three rivers, but their combined drainage area, including very small streams entering the estuary, is only 14.1 mi2

(36.5 km^2). Nevertheless the Webhannet estuary's inlet to the Atlantic, Wells Inlet, is 122 meters wide, over 5 times as wide as the Little River Inlet. This is because the size of an inlet is not a function of the watershed, but rather a function of how large and how open the estuary itself is. The cross-sectional area of a tidal inlet is controlled by the volume of water (known as the tidal prism) that must move in and out of the inlet with each tidal cycle . This is why changes in the morphology of the estuary due to human development or natural vegetative succession can lead to changes in the stability, size and position of a tidal inlet, and to erosion or deposition on the barrier shore around the inlet.

Not all precipitation falling on the uplands is channeled into streams or rivers, and instead travels to the estuary as overland flow (runoff), or infiltrates into the porous glacial sediments and flows to the estuary as groundwater. All surface water, including steams, ponds, freshwater marshes or bogs, is an expression of the intersection of the water table with the surface of the ground, and in Wells NERR it all ultimately flows in response to gravity towards the lowlands and the estuary. The amount of runoff that empties into the estuaries of Wells NERR has been estimated as the equivalent of 51 cm (20 inches) of additional rainfall per year.

Even when we add up all of the freshwater inputs to the Webhannet and Little River estuaries, the volume of freshwater is dwarfed by the amount of salt water moving in and out of the estuaries with each tidal cycle. For example, the annual average discharge of the Webhannet River is 0.6 m per second, or about 1.9 x 10^7 m^3 of freshwater per year. By comparison, the amount of salt water that flows in through Wells Inlet each year is equivalent to 3.5 x 10^9 m^3 of water, which is two orders of magnitude greater than the freshwater input (both fresh and salt water moves out through the inlet with each tidal cycle, of course). The Little River estuary also receives significantly more salt than fresh water. This means that the sedimentary and chemical processes acting in the Webhannet and Little River estuaries are dominated by marine sediment, seawater, and by tidal currents (Mariano and FitzGerald 1989).

Salinity in the Webhannet estuary varies with tide level. At Wells Inlet during 2005, salinity varied between 33.5 psu (practical salinity units) at high tide, a common value for the salinity of seawater in coastal waters along the Gulf of Maine, and ≈ 28 psu at low tide. Near the head of the estuary at Mile Road, salinity is lower (≈ 18 ppt) during low tide. This minimum salinity is far greater than the salinity of freshwater. During storms and spring freshets salinity in the estuary drops as freshwater influx increases, then rapidly returns to normal levels. Salinity measurements at the inlet over 2005 had a mean of 30.7 and a mode of 31.7 (Ch. 15, Table 15-1).

UPLAND

The uplands of Wells NERR are underlain by the metamorphosed siltstones and mudstones of the Kittery Formation, rock that formed from fine-grained sediments laid down in an ancient sea in a region called the Merrimack Trough around 500 million years ago. These sediments were later folded and fused together during a series of continental collisions. Devonian (about 360 million years ago) granites and Triassic (about 65 million years ago) granites also outcrop near the southern end of the Reserve, at Moody Point (Hussey 1989; Ch. 14, Fig. 14-1).

Elevations in the uplands range from the upland / estuarine margin ecosystem found at ≈ 2.2 meters above sea level to open fields and wooded areas at almost 40 meters elevation (orange and red areas on Fig. 2-7). The modern topography of the uplands was shaped by the last glaciation (which ended regionally about 13,500 years ago) littoral erosion during sea-level fall, and fluvial incision to lowstand. The glaciers exposed and shaped the bedrock in some areas of the coast, while depositing large masses of gravel, boulders, sands and clays called "till" in other areas. Drakes Island is an example of such a till deposit. The steep slope backing much of the Webhannet marsh system is a relict feature called an escarpment, carved out during the last glaciation during a short period of slowing in the drop of sea-level around 13,000 years ago. Shorelines created at that time are prominent near the Wells NERR campus.

Upland soils in Wells NERR are developed on the glacial and glaciomarine material that was deposited during and after the last glaciation. These sediments blanketed the pre-existing landscape with a layer of clay and large, often linear mounds of till. This material has developed into a relatively deep, well-drained soil layer rich in mineral material, called a sandy loam. The Reserve uplands exhibit variations of these soil types, but are generally sandy and well-drained, with low water tables. The extremely good hydraulic conductivity of the soils enhances infiltration of rainwater, resulting in less freshwater runoff and fewer streams draining to the lowlands. In relatively low-lying areas near the salt marsh, waterlogged wooded areas have a lacustrine (lake) soil type or are covered by freshwater peats (often found in the yellow regions on Fig. 2-7).

ADVANCES IN GEOMORPHIC RESEARCH

Modern technology continues to create new opportunities to investigate the complex systems and geomorphic evolution of Wells NERR. Side-scan sonar, single-beam sonar and interferometric sonar are all used to map the bathymetry and reveal the characteristics of the seafloor. SONAR (Sound Navigation And Ranging) works by releasing a pulse of energy which is then reflected back to a receiver by the bottom, a form of echolocation. By measuring the travel time of the pulse, scientists are able to calculate the distance to the bottom at that point. Changes in the energetic qualities of the pulse reflect different properties of the seafloor that can be interpreted as sand, gravel, mud or bedrock. This technology allows us to "see" large sections of the seafloor in great detail.

A similar technology is now used to create very high-resolution maps of topography on land. LIDAR (LIght Detection And Ranging) works on much the same principle as does SONAR. A beam of energy (light) is released from an airplane, which is equipped with sophisticated sensors to detect the reflected energy. The travel time is used to determine distance, while changes in the physics of the light can be used to interpret a number of different properties, such as vegetation type. Currently, LIDAR surveys are being utilized to enhance studies ranging from investigations in vegetative succession to the distribution of sediment from winter storms and ice rafts. The use of LIDAR has facilitated a new level of detail in geomorphologic studies, and will be increasingly useful to scientists working at Wells NERR.

REFERENCES

Adam, P. 2002. Saltmarshes in a time of change. Environmental Conservation, 29(1): 39-61.

Argow, B.A. 2007. Winter processes of New England salt marshes. Dissertation, Boston University, Boston, MA.

Argow, B.A., and D.M. FitzGerald. 2006. Winter processes on northern salt marshes: evaluating the impact of in-situ peat compaction due to ice loading, Wells, ME. Estuarine Coastal and Shelf Science. 69 (3-4): 360-369.

Bagwell, C.E., and C.R. Lovell. 2000. Persistence of selected *Spartina alterniflora* rhizoplane diazotrophs exposed to natural and manipulated environmental variability. Applied and Environmental Microbiology 66(11): 4625-4633.

Belknap, D.F., Kelley, J.T. and FitzGerald, D.M. 1995. Barriers and inlets of southern Maine - evaluation of sediment budgets and human influences. New England intercollegiate geological conference guidebook to field trips in north-central Maine, 86th Annual Meeting.

Boon, J.D., III, and R.J. Byrne. 1981. On basin hypsometry and the morphodynamic response of coastal inlet systems. Marine Geology 40: 27-48.

Bricker-Urso, S., S.W. Nixon, J.K. Cochran, D.J. Hirschberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. Estuaries 12(4): 300-317.

Byrne, R.J., and J. Zeigler. 1977. Coastal engineering study, Wells Harbor, Maine. U.S. Army Corps of Engineers, New England Division, Waltham, MA. 89 pp.

Callaway, J.C., R.D. DeLaune, and W.H. Patrick. 1997. Sediment accretion rates from four coastal wetlands along the Gulf of Mexico. Journal of Coastal Research 13(1): 181-191.

Church, J.A., J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M.T. Nhuan, D. Qin, and P.L. Woodworth. 2001. Changes in Sea Level. *In* Climate Change 2001: The scientific basis, contribution of working group I to the third assessment report of the intergovernmental panel on climate change. *Edited by* Houghton, Y.D.J.T., D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu. Cambridge University Press. pp. 638-689.

Dickson, S.H. 2003. Coastal Geology. *In* Geological Society of Maine 2004 Short Course: Geology of Maine. Available at http://www.gsmmaine.org/abstracts.html. Acessed 5 January 2006.

Dionne, J.C. 1989. An estimate of shore ice action in a Spartina tidal marsh, St. Lawrence Estuary, Quebec, Canada. Journal of Coastal Research 5(2): 281-293.

Donnelly, J.P., and M.D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. Proceedings of the National Academy of Sciences 98(25): 14218-14223.

Duffy, W., D.F. Belknap, and J.T. Kelley. 1989. Morphology and stratigraphy of small barrier-lagoon systems in Maine. Marine Geology 88: 243-252.

FitzGerald, D.M., and I.V. Buynevich. 2006. Model of tidal inlet and barrier island dynamics in a regime of accelerated sea-level rise. Journal of Coastal Research (Special Issue 39): 789-795.

Foote, A.L., and K.A. Reynolds. 1997. Decomposition of saltmeadow cordgrass (Spartina patens) in Louisiana coastal marshes. Estuaries 20(3): 579-588.

Gabrey, S.W., and A.D. Afton. 2001. Plant community composition and biomass in Gulf Coast chenier plain marshes: responses to winter burning and structural marsh management. Environmental Management 27(2): 281-293.

Gehrels, W.R. 1994. Determining relative sea-level change from salt-marsh foraminifera and plant zones on the coast of Maine, USA. Journal of Coastal Research 10: 990-1009.

Gehrels, W.R. 1999. Middle and late Holocene sea-level changes in eastern Maine reconstructed from foraminiferal saltmarsh stratigraphy and AMS 14C dates on basal peat. Quaternary Research 52: 350-359.

Gehrels, W.R. 2000. Using foraminiferal transfer functions to produce high-resolution sea-level records from salt-marsh deposits, Maine, USA. The Holocene 10: 367-376.

Gehrels, W.R., D.F. Belknap, and J.T. Kelley. 1996. Integrated high-precision analyses of Holocene relative sea-level changes: lessons from the coast of Maine. Geological Society of America Bulletin 108: 1073-1088.

Goodman, J.E., M.E. Wood, and W.R. Gehrels. 2006. A 17-year record of sediment accumulation in the salt marshes of Maine (USA). Marine Geology: *In* press.

Gornitz, V., 1995. Sea-Level Rise - a Review of Recent Past and near-Future Trends. Earth Surface Processes and Landforms, 20(1): 7-20.

Gulf of Maine Ocean Observing System (GoMOOS). Available http://www.gomoos.org. Accessed 15 December 2006.

Hussey, Arthur M., II, 1989 , Geology of southwestern coastal Maine, in Anderson, Walter A., and Borns, Harold W., Jr., *editors*. Neotectonics of Maine: studies in seismicity, crustal warping, and sea level change: Maine Geological Survey (Department of Conservation), Bulletin 40, p. 25-42

Jacobson, H.A. 1988. Historical development of the saltmarsh at Wells, Maine. Earth Surface Processes and Landforms 13: 475-486.

Kelley, J.T. 1987. An inventory of coastal environments and classification of Maine's glaciated shoreline. *In* Glaciated Coasts. *Edited by* FitzGerald, D.M. and P.S. Rosen. Academic Press, San Diego, CA. pp. 151-176.

Kelley, J.T., W.A. Barnhardt, D.F. Belknap, S.M. Dickson, and A.R. Kelley. 1988. The seafloor revealed: the geology of the northwestern Gulf of Maine inner continental shelf. Open File Report 96-6. Maine Geological Survey, Augusta, ME. 55 pp.

Kelley, J.T., W.R. Gehrels, and D.F. Belknap. 1995. Late Holocene relative sea-level rise and the geological development of tidal marshes at Wells, Maine, USA. Journal of Coastal Research 11(1): 136-153.

Kennish, M.J. 2001. Coastal salt marsh systems in the US: A review of anthropogenic impacts. Journal of Coastal Research 17(3): 731-748.

Leonard, L.A. 1997. Controls of sediment transport and deposition in an incised mainland marsh basin, southeastern North Carolina. Wetlands 17(2): 263-274.

Leonard, L.A., A.C. Hine, and M.E. Luther. 1995. Surficial sediment transport and deposition processes in a Juncus roemerianus marsh, west-central Florida. Journal of Coastal Research 11(2): 322-336.

Leonard, L.A., and M.E. Luther. 1995. Flow hydrodynamics in tidal marsh canopies. Limnology and Oceanography 40(8): 1474-1484.

Mariano, C.G., and D.M. FitzGerald. 1989. Sediment transport patterns and hydraulics at Wells inlet, Maine. Boston University, Boston, MA. 143 pp.

Miller, G.T. 1998. Deglaciation of Wells Embayment, Maine: interpretation from seismic and side-scan sonar data. Masters Thesis, University of Maine, Orono, ME. 231 pp.

Ollerhead, J., D. van Proosdij, and R.G.D. Davidson-Arnott. 1999. Ice as a mechanism for contributing sediments to the surface of a macro-tidal saltmarsh, Bay of Fundy. Canadian Coastal Conference: 345-358.

Redfield, A.C. 1972. Development of a New England salt marsh. Ecological Monographs 42: 201-237.

Reed, D.J. 1995. The response of coastal marshes to sea-level rise; survival or submergence. Earth Surface Processes and Landforms 20(1): 39-48.

Reed, D.J. 2002. Sea-level rise and coastal marsh sustainability: geological and ecological factors in the Mississippi delta plain. Geomorphology 48(1-3): 233-243.

Rybczyk, J.M., and D.R. Cahoon. 2002. Estimating the potential for submergence for two wetlands in the Mississippi River Delta. Estuaries 25(5): 985-998.

Timson, B.S., and D. Kale. 1976. Historical changes of the Webhannet River inlet. U.S. Army Corps of Engineers, New England Division.

Titus, J.G. 1990. Greenhouse effect, sea level rise, and barrier islands; case study of Long Beach Island, New Jersey. Coastal Management 18(1): 65-90.

van de Plassche, O., K. van der Borg, and A.F.M. Jong. 1988. Sea level-climate correlation during the past 1400 years. Geology 26(4): 319-322.

Wood, M.E., J.T. Kelley, and D.F. Belknap. 1989. Pattern of sediment accumulation in the tidal marshes of Maine. Estuaries 12: 237-246.

Chapter 3

Climate and Weather

Christopher Cayce Dalton

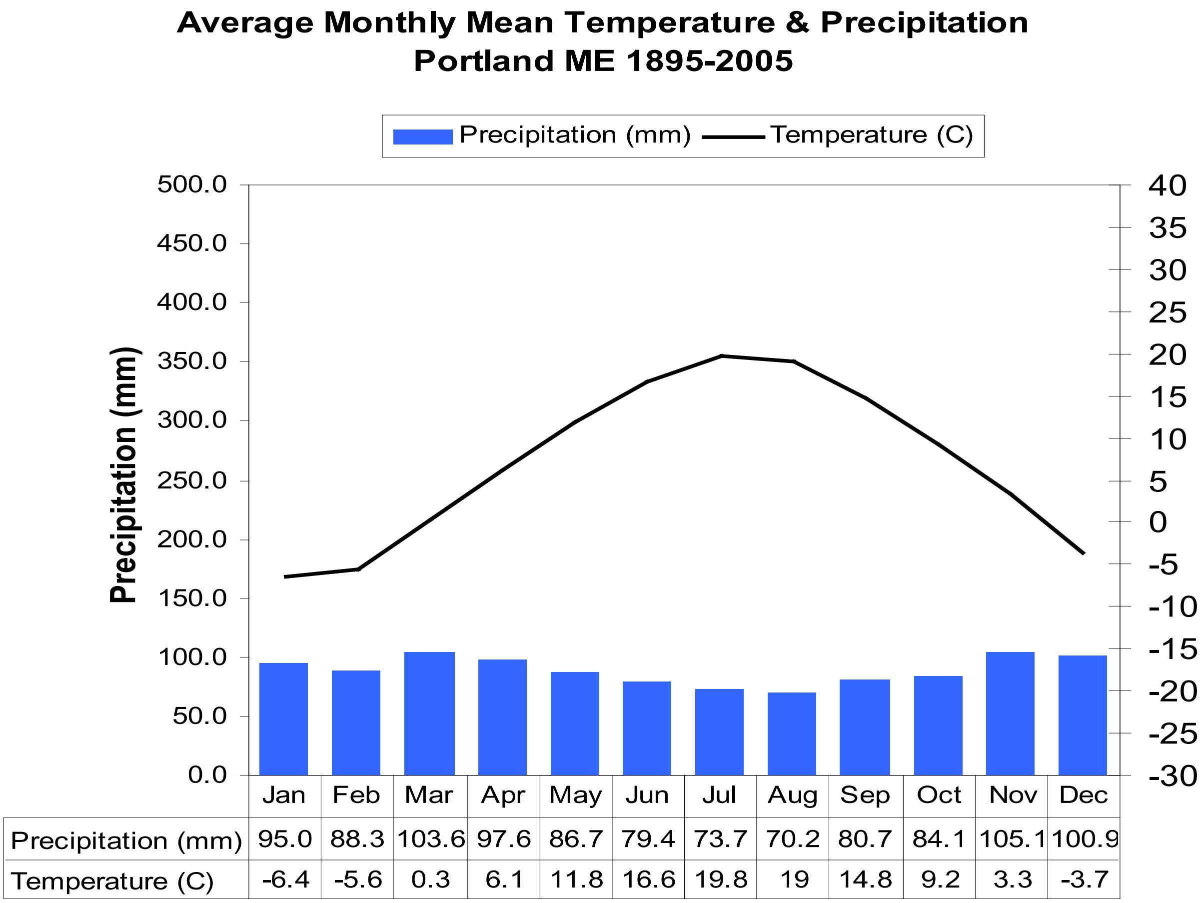
The Maine coast has inspired artists and naturalists for centuries with mild summers, cool sea breezes and stunningly beautiful autumns. The ample year-round precipitation arrives in many forms, as a summer squall, a sea-driven winter storm, or gentle spring rains. The barely temperate climate borders boreal conditions to the north and west, and as a result the Reserve's watersheds host ecological elements of both climatic regimes. Despite temperatures being moderated by the ocean to some degree, winter is nonetheless long and harsh.

In nine years of operation (January 1997 through December 2005), the Reserve's weather station indicates average annual temperatures ranging from 7.2° to 9.6°C. Twelve weeks per year show an average temperature below freezing, and the warmest eight weeks of the year average around 20°C. The minimum and maximum recorded temperatures during this period are -26.0° and 37.6°C. Year-round residents can expect spells of both frigid cold and sweltering heat.

A century of recorded weather in nearby Portland, Maine, (about 40 km northeast of Wells) provides sufficient data for a broad classification of the region's climate (Fig. 3-1). Southern Maine falls in the category "Dfb" according to the Köppen-Geiger Climate Classification System (FAO 1997). That abbreviation indicates cold (in the coldest month average temperature less than -3°C, in the warmest month over 10°C), wet (at least 30mm of rain in driest month, with little precipitation variability from month to month, see Fig. 3-2), with a cool summer (average monthly temperatures less than 22°C).

The Maine State Climatologist, Professor Gregory A. Zielinski, provides a more precise description of the southern Maine coast's climate. He states (units converted to metric):

> *Average monthly temperatures range from 5.8°C in January to 19.3°C in July with daily highs averaging just below freezing in January and lows around 11.7°C . Daily highs in July average around 22.4°C and daily lows around 13.9°C. The sea breeze often keeps daily highs lower during the summer than areas inland. Annual average temperature is 7.0°C. Annual precipitation is 119.5 cm including the*



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	95.0	88.3	103.6	97.6	86.7	79.4	73.7	70.2	80.7	84.1	105.1	100.9
Temperature (C)	-6.4	-5.6	0.3	6.1	11.8	16.6	19.8	19	14.8	9.2	3.3	-3.7

Figure 3-1: Climograph for Portland, Maine. Data NOAA, National Climate Data Center.

water equivalent of snowfall, with monthly averages ranging from 7.6 cm in July to 12.1 cm in October. August receives just 7.7 cm on average. Annual snowfall is around 168 cm. Cool ocean temperatures keep down the number of afternoon showers and especially thunderstorms resulting in low summer precipitation amounts. (Wells NERR 2002)

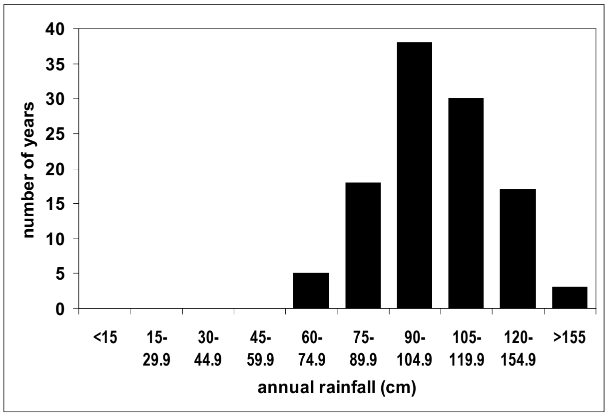


Figure 3-2: Frequency distribution of rainfall at Portland, Maine. Data NOAA, National Climate Data Center.

Data at the Reserve weather station at the Maine Coastal Ecology Center have been collected since January 1997 and formally reviewed and distributed by NOAA Centralized Data Management Office in Charleston, South Carolina, since 2001.

The weather station's latitude and longitude are 43°20' 15.2" N and 70°32' 55.1" W. The wind and solar radiation sensors are mounted on top of a 9.75 m tall telephone pole surrounded by mown grass. The temperature and humidity probes are mounted 3 m high on the north side of the pole. The rain gauge is 2.75 m southeast of the pole, with funnel height of 3 m. Two nearby buildings are potential obstructions, the Coastal Ecology Center (11.3 m to the NW of the pole, 6 m tall, 33.5 m long, oriented NE to SW) and the barn (68 m to the NW of the pole, 11.6 m tall, oriented NE to SW). The annual data set collected is extensive, with fifteen-minute data collection frequency based on a five-second sampling period. The average, maximum, minimum, time of maximum and time of minimum are recorded for every fifteen-minute period for windspeed, air temperature, relative humidity and barometric pressure.

On July 14th, 2006, Wells NERR meteorological station was integrated into the NOAA Integrated Ocean Observing System (IOOS) and the National Weather Service, with the installation of a Campbell Scientific telemetry station. Data are collected every five seconds and output as fifteen minute, hourly, and daily averages, maximums, and minimums. The data are sent hourly to the NOAA GOES East Satellites for transmission to Wallops Island, Virginia, receiving station and the Hydrometeorological Automated Data System (HADS), where the data are uploaded by the Central Data Management Office (CDMO) and posted for viewing by the public. Other organizations that use the data include the United States Coast Guard and the National Weather Service. Data are accessible online at: http://cdmo.baruch.sc.edu/

Annual Weather Patterns

Air Temperature

Winter is the longest season at the Wells National Estuarine Research Reserve. Freezing temperatures on a regular basis arrive about mid-October and persist into the last week of April. The weather station has recorded freezing temperatures as early as October 7th and as late as May 20th. Although average temperatures for the coldest month, January, are just below freezing, extended periods of extreme cold are possible. Seven weeks over the past nine years have had an average temperature of less than -10°C. A brief early-winter warming trend sometimes occurs, and is referred to by residents as a January thaw (Fig. 3-3).

Spring is typically characterized by an extended thaw, as daily highs climb above freezing, then dip back below at night. Ice breaks free from stream banks in early to mid-March, while forests reluctantly surrender their last well-hidden patches of snow as late as early May. Over the course of the winter, the ground tends to freeze to depths of half a meter or more. Warmer temperatures and sunlight thaw the surface first, while frozen soil underneath impedes infiltration of meltwater. The resulting mud defines spring for many residents. Vernal pools (Ch. 10)—an ephemeral aquatic habitat essential to native frogs, salamanders, and fairy shrimp—also result from ample melt water and poor infiltration.

Summer is mild, with peak temperatures typically in the last two weeks of July through the first week of August. Periods of fairly intense high temperatures can occur, although they are usually brief. High temperatures over 30°C, for example, have been recorded at the Reserve just one or two consecutive days at a time, very rarely for three consecutive days, with temperatures almost always dropping to or below room temperature (about 22°C) at night. Consequently, average weekly temperatures exceeded 22°C only during 11 weeks out of the 9-year period, with a maximum average weekly temperature of 23.9°C. By September, a cooling trend is usually noticeable. By late October, the first frost has arrived and autumn begins to resemble what many would consider early winter.

Humidity

Relative humidity remains high during most of the year as one would expect near the ocean. February has the lowest average humidity at 63%, June through August have average humidity around 80%, and September has the highest average humidity at 83%. Relative humidity reached 100% in every month on record at the Reserve, except for January and February 1997 (the record for both months is incomplete). However, dry winds from inland provide occasional periods of low humidity. Most months (96 of 105 months for which we have records, or 91%) show a minimum relative humidity of less than 35%.

Winds

Wind speed and direction follow a clear and gradual pattern over the course of the seasons, as seen in the available data (1997-2005) from the Wells NERR weather station (Figs. 3-4 and 3-5). The winds are generally northerly and westerly in the winter and southerly in the summer, showing a moderate drop in wind speeds during the summer.

Mariano (1988) used weather stations at Brunswick Naval Air Station (80 km to the northeast) and the now former Maine Yankee Nuclear Power Plant in Wiscasset (105 km to the northeast) as representative of the

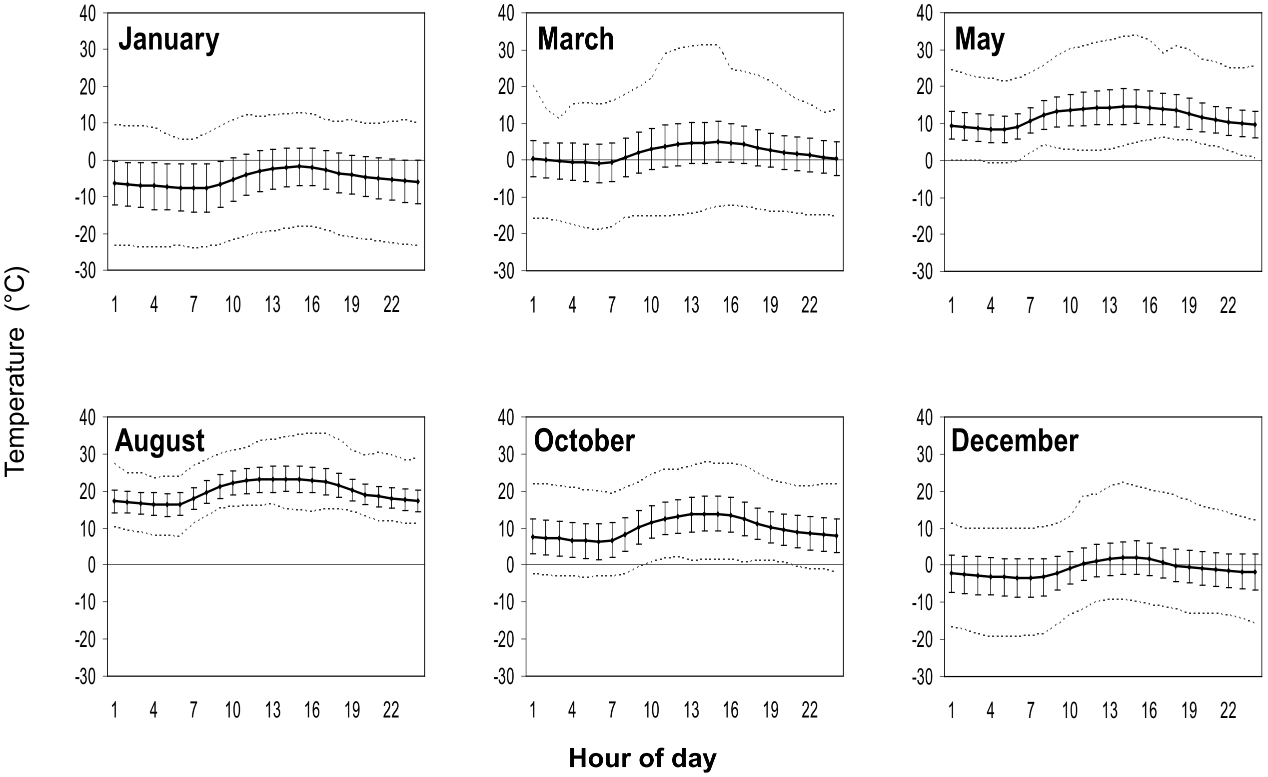


Figure 3-3: Average diurnal air temperature recorded by Wells NERR weather station for selected months from 1997 to 2004. Error bars bracket two standard deviations, dashed lines are minima and maxima.

southern Maine coast. In his analysis, the winter- and early-spring-dominant winds come from the northeast and are associated with low-pressure systems and storms, while the prevailing winds come from the northwest. In the summer and fall, southwest winds prevail driven by continental warming and the Bermuda high pressure system.

In January, winds are predominantly from the west-north-west (about 16% of the time) and north (over 12%), with practically no wind at all coming from the south-east quadrant (Fig. 3-4). Year-round, about 40-50% of wind speeds are in the 2 - 4 m s^{-2}category, so variations in wind speed are noted in the rising and falling patterns of calms and winds greater than 4 m/s. Winds become stronger and more varied in February, setting a pattern that continues in March. Calms are least frequent (2.3% are <0.5 m/s) and heavy winds most frequent (11.3% are >6 m/s) in March. The dominance of northeast winds as cited by Mariano is confirmed by the fact that in January through March most winds greater than 8 m/s come from the northeast quadrant.

In April, the shift toward southerly winds continues (about 10% of winds coming from directly south), although winds from the north and north-west are both more frequent. By May, the southerly wind is predominant, and grows more so in June and July, respectively. From July through September, calm winds are more frequent with only about 10% of winds stronger than 4 m/s (Fig. 3-5). These stronger winds account for over 20% of measurements from October through the end of the year. Also by October, the southerly winds are among the least frequent, practically disappearing by December, replaced once again by winds from the northwest quadrant.

Solar Radiation

Based on the Wells NERR weather station, it is difficult to draw conclusions about photosynthetically active radiation (PAR), because three years of data are missing, 2001-2003. This leaves only one year (2004) of data which has been reviewed by CDMO available at the present. Using all six years available, both reviewed and unreviewed, it appears that PAR generally follows a regular sinusoidal

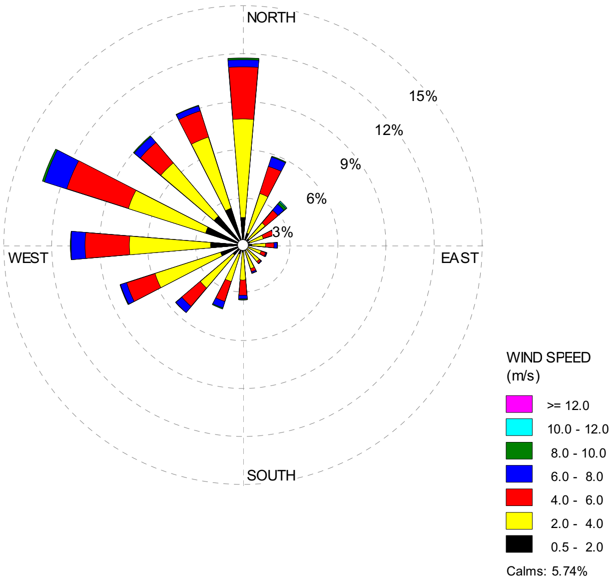


Figure 3-4: Wind rose diagram for January through March winds, 1997-2005. Data Wells NERR.

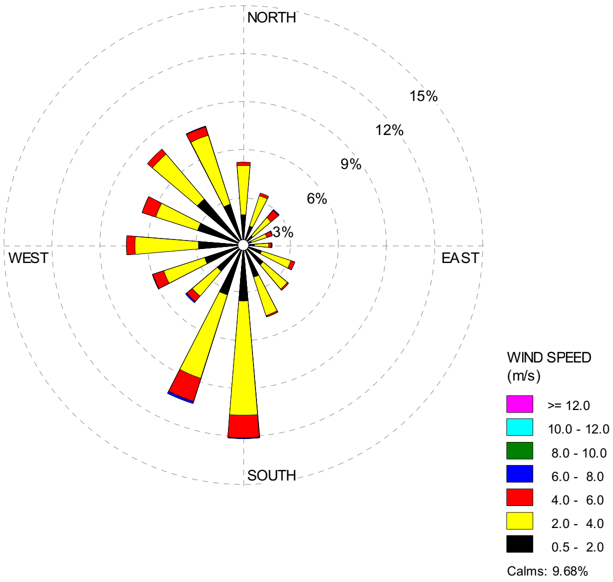


Figure 3-5: Wind rose diagram for July through September winds, 1997-2005. Data Wells NERR.

pattern, peaking at the summer solstice. There appears to be moderate reduction in PAR in the first few weeks of July, perhaps due to fog as newly warmed inland air meets the still cold air at the ocean's surface.

STORMS AND ICE

Storms are a constant risk along the coast of Maine. A frequent type of winter and early spring storm comes from the northeast and typically brings a period of more or less constant precipitation that can last for several days. These extra-tropical storms are known as "nor'easters."[1] Most beach erosion occurs when strong storms from the northeast coincide with spring tides (Montello 1992).

In the summer, warm air from inland can meet cold Gulf of Maine waters, resulting in dense fog. Another result of the clash between warm and cool air is frequent thunderstorms throughout the summer and fall. These mercurial storms are sometimes accompanied by strong winds and hail. Severe winds have downed trees and power lines and closed roads to Wells NERR on three occasions in the past five years. One of these, the severe storms of May 2006, destroyed Skinner Mill Bridge, just a few hundred feet from the entrance to Wells NERR and washed out many other roads and bridges across the region.

The timing and nature of precipitation has a profound effect on the winter landscape. A heavy snowfall followed by steady cold temperatures can mean a protective blanket of snow which lasts through April, insulating the ground and buildings against the extreme lows of the season. On the other hand, rain or sleet at the cusp of a cold spell can create an almost impenetrable sheet of ice whose weight damages vegetation and property

An old maple tree felled by 48 mph gusts in May 2005. Photo Cayce Dalton.

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[1] The term "nor'easter" is not a traditional New England term, despite ubiquitous use by meteorologists today in the region and beyond. A more appropriate regional colloquialism might be "noth-easter," though by now use of the former term seems intractable. See New Yorker Magazine, 5 September 2005.

Research Associate James Dochtermann kneels beside a block of snow and ice on the Little River. The underside of such blocks can grip and uproot vegetation when displaced by high tides in spring. Photo Cayce Dalton.

and whose slick surface never seems to vanish completely regardless of later snowfall.

During most winters, thick ice covers the smaller tidal channels and much of the marsh surface in the estuaries. In the Webhannet, the shallow and wide main channel generally remains clear, since it is well flushed by warmer seawater. In the Little River, much less of the estuary remains open. During high tide, channels in the marsh surface may disappear from sight under a seemingly uniform plain of ice and snow extending across the estuary. At low tide ice tends to collapse down to the water surface, although it is locked in place by surrounding sheets and unable to float downstream.

Ice formation and movement in nearby Great Bay Estuary in New Hampshire (35 km southwest) was shown to have a strong influence on sediment movement and shoreline shape, especially on soft mud tidal flats, generating erosion at the inner flat and deposition at the outer flat, with a net tendency toward erosion. Clumps of vegetation and sediment are also gripped by ice, ripped up and floated to new locations (Short 1992). Argow (2007) proposed that ice movement in the estuary can also be a source of sediments to the marsh, adding half of the new inorganic material deposited each year and helping to increase vertical accretion (see Ch. 14).

VARIABILITY

New England weather is considered by many to be mercurial, subject to rapid, sometimes dramatic fluctuations. Sudden sea squalls and terrestrial dust devils are the stuff of Maine legends, no less so at the Wells National Estuarine Research Reserve. Tall tales aside, the weather station at the Wells NERR lends some credence to this reputation for weather turning on a dime. In 2004, the maximum change in temperature over a fifteen-minute period for that year occurred on May 11 at around noon. A closer look at the minimum and maximum temperatures recorded during that quarter of an hour reveals that 27.1°C (80.8°F) at 12:09 dropped to 14.7°C (58.4°F) at 12:23. That's a change of 12.4°C (22°F) in fourteen minutes. Such a dramatic change in recorded temperature naturally brought to mind questions about the accuracy of the equipment, but since it coincided with a 180° shift in winds, from land to sea breeze, it was retained in the record as valid.

TOPICS FOR FUTURE RESEARCH

Without a doubt, the key scientific questions in meteorology revolve around human-induced climate change. Scientists, lawmakers and residents of southern Maine have many reasons to keep a careful eye on global warming. From an ecological point of view, much of southern Maine's diversity is based on the intersection of two climate regimes, temperate and boreal. Warming temperatures may move that intersection away from this region. Additionally, rising sea level (Slovinsky, Dickson, Maine Geological Survey; see Fig. 3-6) or an increase in the intensity of storms would threaten not only property and tourism, but also the marsh ecology. Creating a complete and long-term record of weather at the Wells National Estuarine Research Reserve is the first step toward learning how that weather is changing through time.

Figure 3-6: Projected extent of flooding given a 0.3m (1 ft) sea level rise at Drakes Island, Wells, Maine. "HAT" refers to "highest annual tide." Map courtesy of Peter A. Slovinsky, Stephen M. Dickson, and the Maine Geological Survey.

References

Argow, B.A. 2007. Winter processes of New England salt marshes. Dissertation, Boston University, Boston, MA. 379 pp.

Food and Agriculture Organization (FAO) of the United Nations. 1997. Sustainable Development Department. Brief guide to Koeppen Climate Classification System. http://www.fao.org/sd/EIdirect/climate/EIsp0066.htm, accessed 17 April 2006.

Mariano, C.G. and D.M. FitzGerald. 1988. Sediment transport patterns and hydraulics at Wells Inlet, Maine. Report to NOAA National Marine Sanctuary Program. 143 pp.

Montello, T.M., D.M. FitzGerald, S. van Heteren, D.W. Caldwell and L.K. Fink Jr. 1992 Stratigraphy and evolution of the barrier system along the Wells-Ogunquit embayment in Southern Maine. Coastal Environmental Research Group, Dept. Geology, Boston Univ. Technical Report No. 15. 142 pp.

National Oceanic and Atmospheric Administration, National Climatic Data Center. US Climate Data at a Glance http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html, accessed April 17, 2006.

Short, F.T. 1992, e*ditor*. The ecology of the Great Bay Estuary, New Hampshire and Maine. an estuarine profile and bibliography. NOAA – Coastal Ocean Program Pub l. 222 pp.

Wells National Estuarine Research Reserve. 2002. System Wide Monitoring Program meteorological metadata. http://cdmo.baruch.sc.edu/

CHAPTER 4

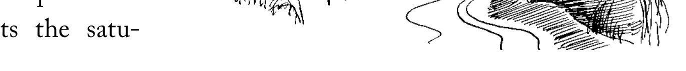
Hydrogeography

MATTHEW MCBRIDE

LITTLE RIVER WATERSHED

The Little River Watershed covers 26 mi2, and is formed by the Merriland River and the Branch Brook which converge within the estuary to form the Little River prior to emptying into the Atlantic Ocean (Fig. 4-1). The Merriland River and the Branch Brook have their headwaters in the sandy outwash plains in the towns of Sanford and Wells near the Sanford Municipal Airport, and flow southeast towards the Atlantic Ocean. The Merriland River has a drainage area of 12.8 mi2 starting in Sanford and continuing through Wells. The Branch Brook has a drainage area of 12.24 mi2 starting in Sanford and traveling between the towns of Wells and Kennebunk serving as the town line.

The Branch Brook is predominantly a ground water stream with the majority of its baseflow derived from groundwater discharge (D'amore 1983). The majority of the brook consists of a 15 to 30 m thick sand and gravel aquifer underlain by silts and clays of the Presumpscot Formation which limits the saturated thickness of overlaying outwash. "D'Amore (1983) demonstrated that the Great Sanford Outwash Plan moderates stream flow in the Branch Brook by absorbing much of the rainfall during storms, and then slowly discharging to the stream via baseflow" (Kuo 1998). The Branch Brook also serves as the primary water supply for a population that varies seasonally from 28,000 in the winter to over 75,000 in the summer in the Towns of Kennebunk, Kennebunkport, Wells, Ogunquit, and portions of Arundel, Biddeford, and York. The Merriland River bed is composed of glacial till, stratified sand and gravel, and the Presumpscot Formation clay with a series of end moraines (Kuo 1998). The Merriland River travels downstream through elevated land to Hobbs Pond, a pond created by a mill dam in the stream. Once beyond Route 1, the land flattens as it flows into the Little River estuary. A land cover analysis based on 1991 aerial photography described the Little River watershed as 1.8% water, 6% developed land, 8.1% hay, pasture and mowed land, and 84.3% woodlands (Holden 1997).



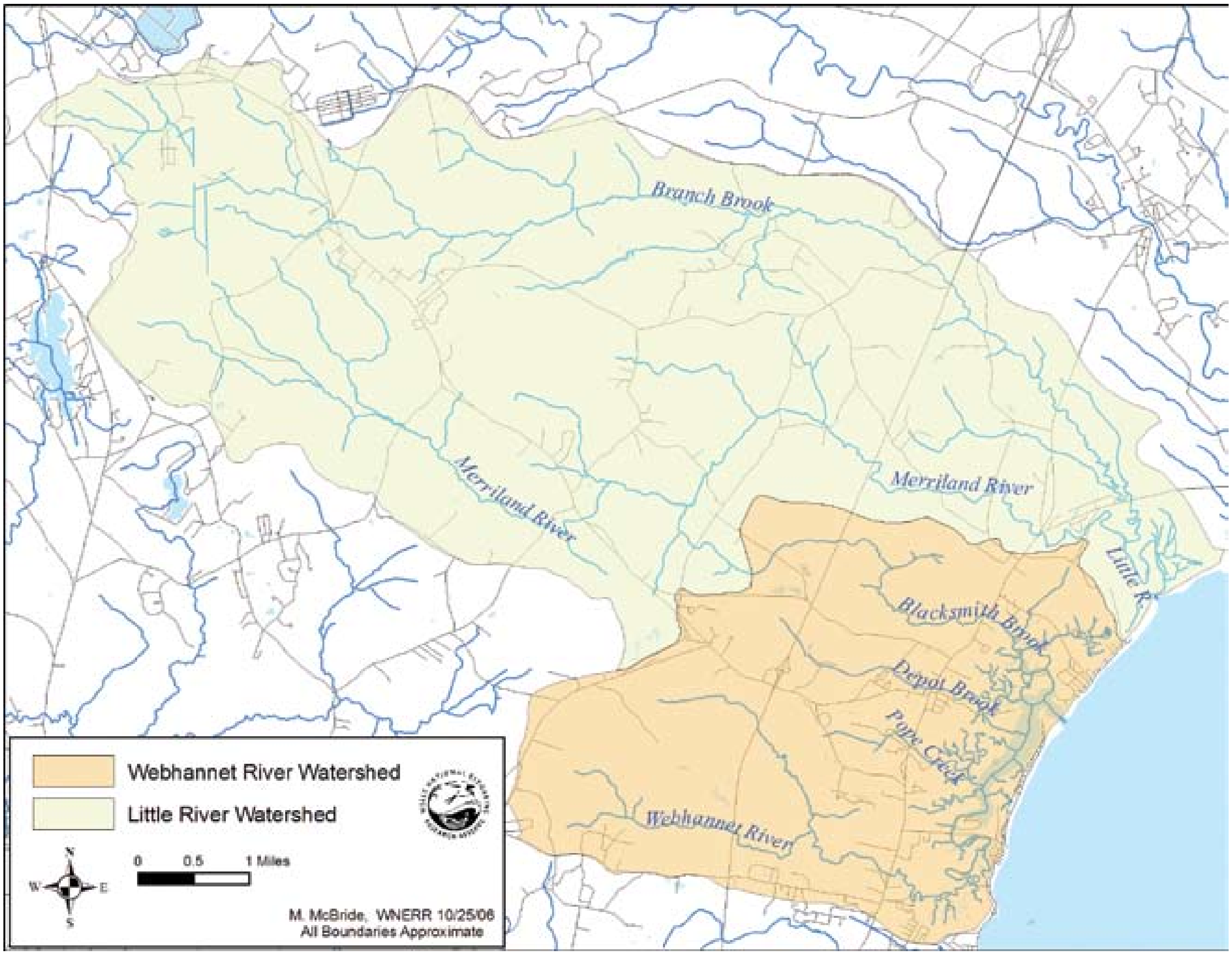


Figure 4-1: Watershed map of the Webhannet and MBLR estuaries.

Flow Alterations in the Merriland River, Branch Brook, and Little River (MBLR) Watershed

Man-made structures often have the unintended consequence of seriously altering the hydrology and connectivity of streams. The structures in the Merriland and Branch Brook watershed include two dams where impounded water affects the flows in the system. One dam is in the upper reaches of the Merriland River and forms Hobbes Pond. The dam not only restricts flow to create the pond, but also presents an obstacle to fish attempting to move upstream to feed or spawn. The pond is the result of a large stone dam just west of Hobbs Farm Road which creates a 5 m drop downstream. The second dam is the remnants of the Skinner Mill dam which creates a half meter drop into the stream channel jut before the confluence of the two rivers. In its current configuration, the dam potentially prevents anadromous fish such as alewife and rainbow smelt from migrating upstream and spawning, since the drop in the channel lacks the boulders and associated pools that would allow fish to make their way up and over this relatively low obstacle.

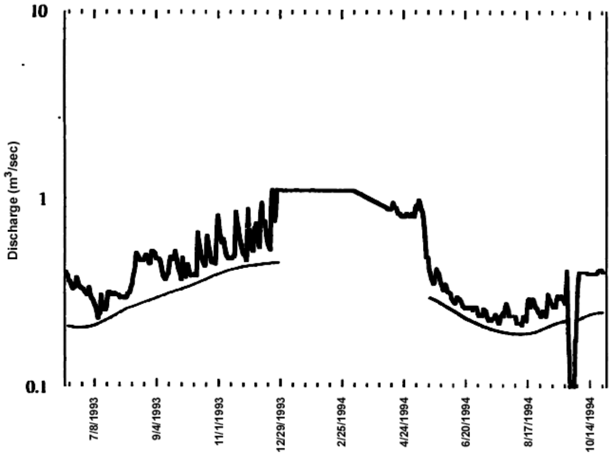


Figure 4-2: Webhannet River discharge for period 1992-1994 (Kuo 1998).

On Branch Brook, the Kennebunk, Kennebunkport and Wells Water district (KKWWD) maintains a dam creating a reservoir from which water is withdrawn for treatment and public distribution. Since Branch Brook flows through primarily glacial sand deposits, the sediments that would normally flow downstream are deposited behind the dam and have to be periodically dredged and deposited in the flood plain. This prevents needed sediments from being deposited in the Little River Estuary, where they would become incorporated into the marsh peat and contribute to the process of accretion, important in preventing potential detrimental effects of sea level rise.

Little River Inlet and Estuary Morphology

The Little River inlet has a double spit barrier beach morphology, with Crescent Surf Beach to the north and Laudholm Beach to the south. The inlet is prone to morphological changes due to storm and accretionary processes. The mean annual discharge of the Little River is estimated to be 1.4 m sec^{-1} over a half tide cycle (6.2 hrs). The freshwater contribution of the Little River comprises a relatively large percentage (11%) of the bay tidal prism. The freshwater discharge at the inlet is most noticeable at the end of the ebb cycle when the channel waters are brackish to almost fresh on occasion. During winter cold snaps, the back barrier channel completely freezes over (FitzGerald and Mariano 1989).

Water Quality in the Estuary

The results of a statewide estuarine water quality survey coordinated by Wells NERR in 1995 and 1996 (Kelly 1995, Kelly 1996) suggest that the Little River estuary may be more susceptible to nutrient enrichment from watershed inputs than most Maine estuaries. This susceptibility is attributed to the system's geomorphology, having a large watershed discharge (e.g. water flow) into an estuary with a relatively small tidal volume. The estuary showed thermal stratification in the summer, and low dissolved oxygen below the chemocline, the transition zone between the upper fresh water layer and the lower salt water layer.

WEBHANNET RIVER WATERSHED

The watershed of the Webhannet River estuary consists of six streams, four of which are named: Webhannet River (see photo), Popes Creek, Depot Brook, and Blacksmith Brook. The Webhannet River provides 55% of the total freshwater discharge into the estuary, Blacksmith Brook 25%, and the other four streams the remaining 20% (Ward 1993). The Webhannet River is the primary source of freshwater to the estuary (Fig. 4-2, Fig. 4-3). The Webhannet River watershed covers 3549 ha. The land use within the watershed (from 1991 photos) is predominantly woodland at 63.7%. The remaining

Banks of the MBLR watershed. Photo Wells NERR.

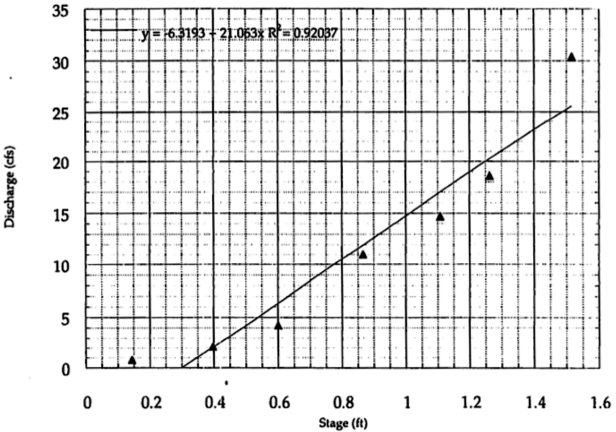
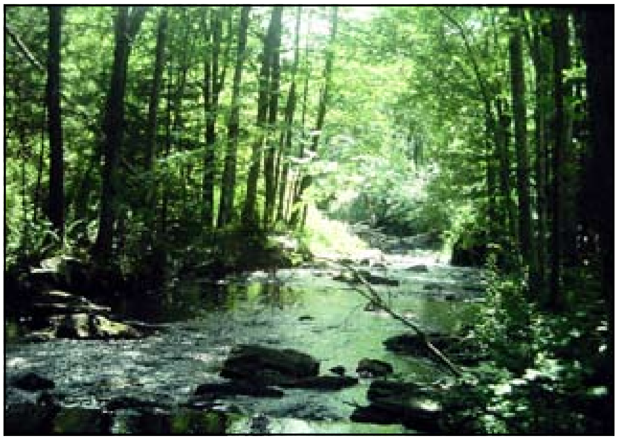


Figure 4-3: Rating curve for the Webhannet River made with data collected 1992-1994 (Kuo 1998). The equation of the line is $y=-6.3193-21.063x$, where y is discharge in ft^3 s^{-2} and x is the stage in feet. The R^2 value is 0.9.

acreage is covered by developed land at 18.6%, water (wetland, fresh water, tidal marsh and beach) at 35%, and hay, pasture, mowed land at 2.8%. The Webhannet watershed has a significantly higher percentage of developed land than the neighboring Little River watershed (18.6% versus 5.7%) and of that developed land, a large portion falls into the high-density developed land category (10.1%) while the Little River watershed has 0% in that category (Holden 1997). High-density development is an important factor in the Webhannet watershed. Development is concentrated along the Route 1 corridor and east to the ocean. The tributaries of the Webhannet River system flow across sand and gravel deposits near the headwaters and the impermeable sandy muds of the Presumpscot Formation in the lower reaches similar to the MBLR watershed (Belknap *et al.* 1997).

Flow Alterations in the Webhannet Watershed

Several areas of major human disturbance are evident in the Webhannet marsh. There are currently three causeways separating the Webhannet River marsh into four subsections. The Mile Road causeway includes a wide bridge, so channel flow is not severely restricted. The Lower Landing Road causeway and the dredge spoil pile have no bridge or culvert, and there is clear evidence of alteration of drainage (Jacobson 1988). The northern Drakes Island Road causeway, built at the turn of the 20th century, once included a tidal gate, resulting in exclusion of a portion of the Webhannet marsh from tidal inundation. This gate was destroyed in a storm in the last decade, but the remaining culvert still restricted free tidal exchange. The culvert was replaced in 2005 with a self-regulating tide gate and is in the process of being evaluated for its effect in restoring tidal flow to the impounded portion of the estuary. The dredge spoil pile, containing about 500,000 m^3 of sand, has severely impacted the marsh, both by directly covering approximately 12.3 ha (123,000 m^2) of marsh with 4 m or more of sand, but also by subsidence effects (see photo). The marsh drainage is altering rapidly both north and south of the dredge-spoil pile in response to compaction of the peat under the dredge spoil, altering microenvironments in the vicinity (Jacobson 1988, Kelley *et al.* 1995, Belknap *et al.* 1997).



The Webhannet River, the largest of five tributaries to the Webhannet Estuary. Photo Michele Dionne.

Aerial view of Wells Harbor and dredge spoil in the Webhannet Estuary. Photo Wells NERR.

Webhannet River Inlet and Estuary Morphology

"The marsh system at Wells Inlet consists primarily of supratidal marsh, intertidal flats and an incising network of tidal creeks. The entire back barrier has an area of 4.91 km^2, of which 0.22 km^2 is open water area, 1.43 km^2 intertidal sand and mud flats, and 3.26 km^2 *Spartina patens*" (Mariano 1989). "Wells Inlet flows between these two spit systems and is classified as one of Maine's large tidal inlets (throat width of 122 m) (FitzGerald *et al.* 1988). The yearly average freshwater discharge of the Webhannet River is 0.6 m sec^{-1}. which yields a volume of 1.3 x 10^4 m^2 during a half tidal cycle (6.2 hrs.). Because this influx of freshwater is two orders of magnitude less (0.5%) than the saltwater tidal prism (2.4 x 106 m3), Wells Inlet and its back barrier region are dominated by tidal currents and tidally induced processes. Estuarine conditions, in terms of stratified flow, and estuarine sedimentation processes, would only be expected during intense precipitation events and spring freshets" (Mariano 1989).

These numbers are currently under revision through the Reserve's recent vegetation mapping effort.

Surficial Geology of the Webhannet and Little River Estuaries

The Late Wisconsin ice sheet advanced from the northwest across what is now Maine to the terminal position on the continental shelf. The retreat of the ice sheet and post-glacial marine submergence is recorded in southern coastal Maine by a complex succession of glacial and glaciomarine sediments (Smith 1982, 1985). Glacial erosion superimposed a northwest-southeast lineation over the northeast-southwest trending bedrock units. Withdrawal of the marine-based ice in southern Maine appears to have taken place in shallow water (less than 10 m). The ice margin remained in the position of the present coastline at approximately 13,200 B.P. (Smith 1982, 1985). Subsequently, retreat accelerated, so that the ice front reached a position above the marine limit along the entire Maine coast between 12,600 B.P. and 12,400 B.P. The southern coastal zone then emerged as a result of isostatic rebound by 11,500 B.P. (Smith 1982, 1985). Stratigraphic glacial deposits include glacial till, ice-contact stratified drift, subaqueous outwash, silt and clay of the Presumpscot Formation, and subaerial outwash (Smith 1985). The present glacial till is variable in thickness and composition, and is locally subaqueous, stratified and intermixed with the Presumpscot Formation clays, suggesting glacial ice was in contact with the ocean during the ice retreat. The Presumpscot Formation is a marine deposit of glacial rock flour, occurring as a discontinuous sediment cover up to 50 m thick in the area of late-glacial marine submergence (Smith 1985, Kuo 1998).

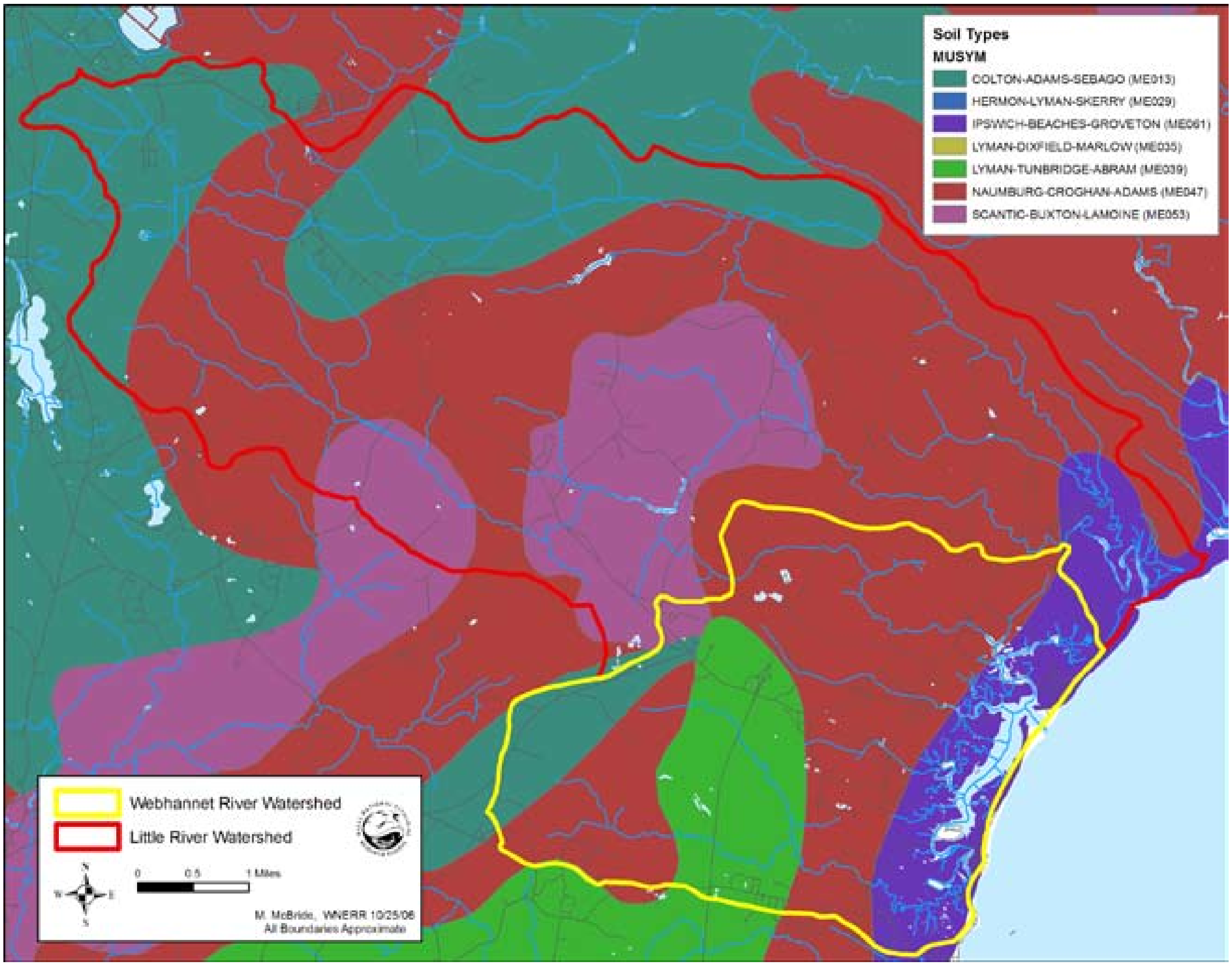


Figure 4-4: Soils map of the Webhannet and MBLR estuaries.

Soils in the Webhannet and Little River Estuary

Soils within the study area were formed during the retreat of the last (Wisconsin) glacier, approximately 12,500 years ago (Fig. 4-4). Material was transported across the region in a generally a northwesterly to southwesterly direction. Soil material formed by the glacier was either deposited as poorly sorted glacial till material containing stones and fragments, or was transported by glacial meltwater or left behind as water-worked glaciofluvial deposits. Marine deposits that had accumulated under seawater were left behind when the land rebounded after the retreat of the glacier. Freshwater (muck and peat) and saltwater deposits formed in wet depressional areas from the accumulation of plant debris (estuaries). Lacustrine deposits formed under freshwater bodies of quiet water. Other than the extensive area of salt marsh on the Reserve, the observed soils are comprised primarily of glacial till material. The developed area of the Reserve, including the knoll on which the Visitor's Center, farm buildings and upland fields are located, is underlain by glacial till identified as Hermon sandy loam. This soil type is deep and somewhat excessively drained. Permeability is rapid to very rapid in the soil profile (McMullin 1996).

REFERENCES

Belknap, D.F., D.C. Smith, and W.R. Gehrels. 1997. Environmental changes in the Wells National Estuarine Research Reserve and Pemaquid Beach salt marshes, Maine, during the past 300 years: implications for restoration of New England-type salt marshes. University of Maine, Orono, ME. 24 pp.

D'Amore, D.W. 1983. Hydrogeology and geomorphology of the Great Sanford Outwash Plain, York county, Maine with particular emphasis on the Branch Brook watershed. Dissertation. Boston University, Boston, MA.

FitzGerald, D.M., and C.G. Mariano. 1989. Tidal hydraulics, morphological changes and sedimentation trends at Little River inlet, Maine. Boston University, Boston, MA. 84 pp.

Holden, W.F. 1997. Fresh water, suspended sediment and nutrient influx to the Little River and Webhannet River estuaries, Wells, Maine. Dissertation. Boston University, Boston, MA. 279 pp.

Jacobson, H.A. 1988. Historical development of the saltmarsh at Wells, Maine. Earth Surface Processes and Landforms 13: 475-486.

Kelley, J.T., W.R. Gehrels and D.F. Belknap. 1995. Late holocene relative sea-level rise and the geological development of tidal marshes at Wells, Maine, U.S.A. Journal of Coastal Research 11(1): 136-153.

Kelly, J.R. 1996. Dissolved oxygen levels in Maine estuaries and embayments. Wells National Estuarine Research Reserve, Wells, ME. 74 pp.

Kuo, C-H. 1998. Quantitative assessment of hydrogeology in the Merriland River, Branch Brook, and Webhannet River Watersheds, Wells, Maine. Dissertation, Dissertation, Boston University, Boston, MA. 223 pp.

Mariano, C.G. 1989. Wave-current interactions at Wells inlet and a comparison of hydraulics and sand circulation with Little River inlet. Masters thesis. Boston University, Boston, MA. 190 pp.

McMullin, G. 1999. High intensity soil survey: Wells National Estuarine Research Reserve. Wells National Estuarine Research Reserve, Wells, ME. 53 pp.

Smith, G.W. 1982. End moraines and the pattern of last ice retreat from central and south coastal Maine. *In* Late Wisconsinan glaciation of New England. *Edited by* Larson, G.J. and B.D. Stone. Kendall-Hunt. pp. 195-209.

Smith, G.W. 1985. Chronology of late Wisconsinan deglaciation of coastal Maine. *In* Late Wisconsinan deglaciation of New England and Adjacent Canada. *Edited by* Borns, H.W., W.B. Thompson and P. LaSalle. Geological Society of America Special Paper 197.

Ward, L.G. 1993. Precipitation, streamflow, and water characteristics (physical and chemical) of the Webhannet River estuary, Wells, Maine. Jackson Estuarine Laboratory, University of New Hampshire Department of Earth Sciences, Durham, NH. 101 pp.

CHAPTER 5

Land Use

TIN SMITH

Two small coastal watersheds (the Webhannet and Merriland River, Branch Brook, and Little River (MBLR)) with a combined drainage of approximately 10,350 ha (40 mi^2) directly influence the estuaries of the Wells Reserve. These two watersheds are similar to numerous other small watersheds that are sandwiched between major rivers (e.g., the Piscataqua and Saco rivers, which carry water from the interior of central New England) and also drain the immediate coastal plain of the Gulf of Maine.

The 3626-ha (14-mi^2) Webhannet watershed is entirely within the town of Wells and nearly square in shape. It predominately drains a sandy outwash plain from the most recent glacial period. There are four nearly equal contributors that form the watershed: Pope's Creek, Depot Brook, Blacksmith Brook, and the Webhannet. All four streams rise just west of the Maine Turnpike and wind their way easterly or southeasterly crossing US Route 1 and flowing into the broad and strongly tidal Webhannet estuary (Smith 2003a).

The Webhannet estuary runs parallel to the shorefront behind heavily developed barrier beaches (Wells and Drakes Island) and includes the actively maintained Wells Harbor before turning and entering the Gulf of Maine through a pair of stone jetties constructed from 1963- 67. The jetties extend 373 meters (Drakes Island) and 396 meters (Wells Beach) into the Wells Embayment.

The Webhannet drains the most commercially and residentially developed areas of the community. It includes stretches of both US Route 1 and Interstate 95 along with several shopping plazas and small malls. The barrier beaches of Wells and Drakes Island are nearly completely built at a high density (2-8 units per acre). The inland marsh edge is quickly being built out – mostly with intensive multi-unit housing projects marketed to visitors and seasonal residents. Views of the marsh and beaches are highly valued and riparian vegetation has been removed or cut back.

The Little River to the north (6,734 ha / 26 mi2)

Early European settlers valued salt marshes as pasture which didn't first require clearing. This view of the Little River shows the contrast between the open salt marsh meadow and surrounding woods. Photo Wells NERR.

is dominated by Branch Brook (3,315 ha / 12.8 mi2) and the Merriland River (3,160 ha / 12.2 mi2). Both tributaries begin in the sandy flat outwash plains of Sanford near the airport and are influenced by the topography and terrain created from glacial deposits as they flow southeast (Smith 2003b, Smith and True 2004).

The Branch Brook watershed consists of fine, medium, and coarse sand intermittently interrupted by bedrock outcrops and till covered knobs. Much of the watershed is dissected by deep, steep-sided streams that cut through the sand and into an underlying clay-silt layer of glacial-marine origin. Branch Brook forms the political boundary between Wells and Kennebunk for most of its length.

The Merriland River bed is composed of glacial till, stratified sand and gravel, and the Presumpscot Formation with a series of end moraines. The flow is interrupted by the dam at Hobbs Pond. Shortly after both rivers cross under Route 1 the land levels off and comes under tidal influence. As the streams enter the estuary their narrow channels meander widely before their confluence, which forms the Little River. The Little River runs the last mile to the Gulf of Maine, where the mouth divides the undeveloped portions of Crescent and Laudholm beaches.

The tidal volume in the Little River is relatively small due to its narrow channel (10-60 meter / 35-200 feet) and short distance (3.6 kilometers / 2.25 miles) to head of tide just below Skinner Mill. There is also a high bar at the mouth that controls the progression of both the falling ebb tide and the rising flood tide (Ch. 15). This bar holds water in the tidal river channel at low tide. The mouth has on occasion moved northward when storm waves over wash the dunes on Crescent Beach but this movement has been temporary.

Both tributaries cross Routes 1, 9, 9A and Interstate 95 but still drain a relatively lightly developed landscape. However, this has been changing in recent years with the construction of intensive seasonal and retirement

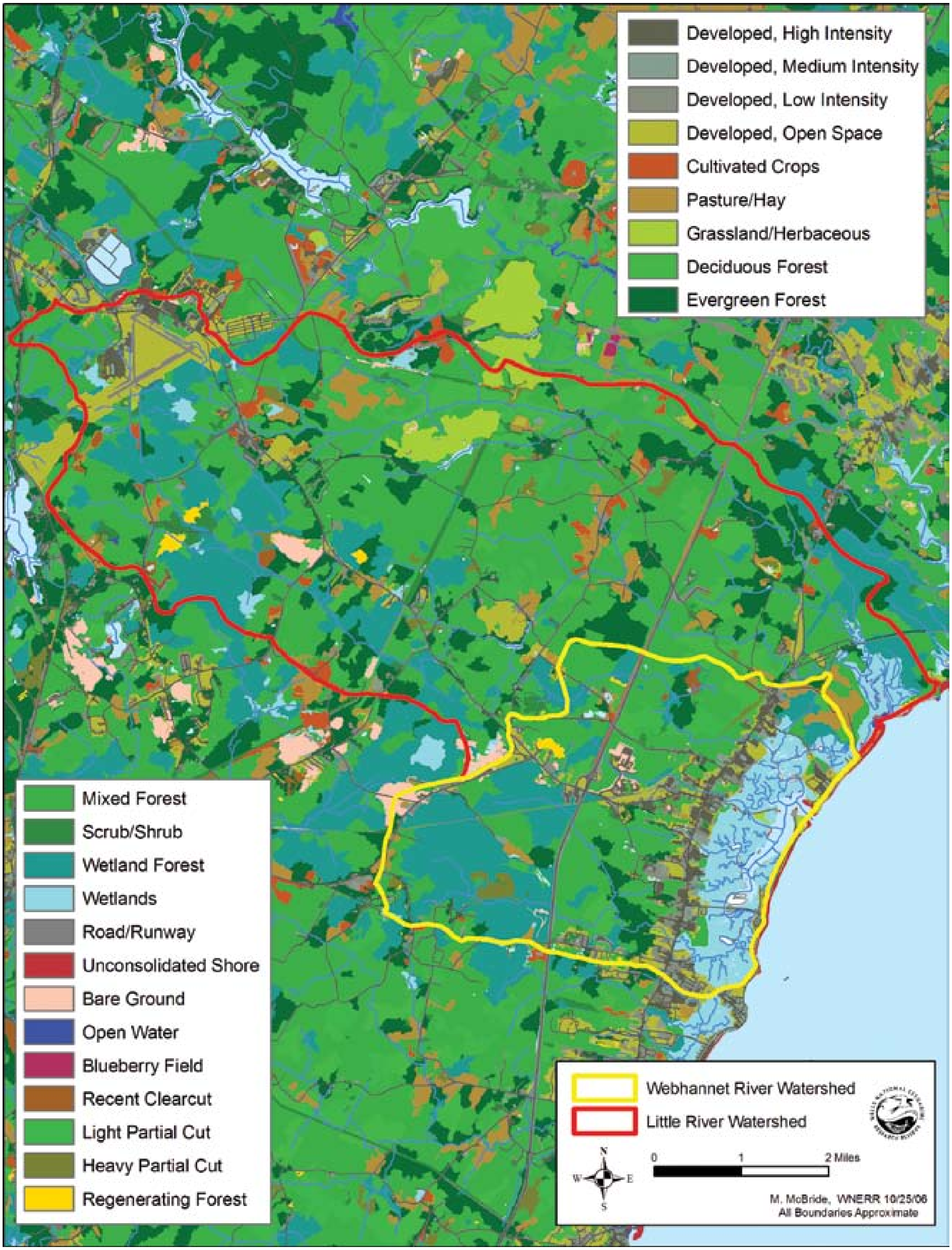


Figure 5-1: Land cover map of Webhannet and MBLR estuaries based on Landsat imagery from 1999-2001. Data Maine Office of GIS, Maine Land Cover Database.

Figure 5-2: Portion of 1891 USGS map showing the Wells NERR estuaries and surroundings.

housing developments where US Route 1 intersects the Merriland River.

LAND AND WATER USE HISTORY

Over the past four centuries human impacts to the landscape evolved from Native American and early European small-scale alteration of land cover (small transitory settlements) to landscape-scale manipulations (farms and towns replacing forest), to the significant replacing of natural cover with increasingly impervious, human-created cover (roofs, lawns, and pavement). This course of events has altered the processes of water interception, infiltration, and runoff that determine the magnitude of flooding, water retention, and water quality. The trends that have most influenced these changes have been population growth, housing, agriculture, forestry, transportation and power. A new emerging trend as the 21st century begins is climate change, also influenced by human action.

Human influences in the Greater Piscataqua region of Maine and New Hampshire have been documented for as long as 11,000 years. Native Americans (Abenaki, Sokaki and Saco peoples) established thriving cultures in the region using the coastal rivers that provided fresh water, transportation routes, abundant fish, shellfish, sites for agriculture and access to lowland wildlife. They minimized the alteration of the landscape through seasonal settlements and migrations.

Martin Pring was the first European to document a visit to this area, exploring the Kennebunk, York, and Piscataqua Rivers in 1603. European immigration in what would become southern Maine began sporadically in the late 1630's and brought a practice of settlement that began similar to the Native Americans but soon differed significantly in several ways. The Town of Wells was founded in 1641.

Early European settlers made their livelihood from the coast, adjacent marshes, and nearby uplands which had been inhabited by Native Americans but largely abandoned as the result of disease epidemics. As all early transportation was by boat, the coastal river mouths served as harbors and the coastal marshes and nearby uplands quickly became the centers of commerce with piers, garrisons, shipyards, roads, and water-powered mills.

The first water-powered mill in Wells was at Webhannet Falls constructed in 1641. In 1692 there were 5 mills on the Webhannet and Little Rivers. The abundant wood supply and a huge demand in both Europe and the Caribbean for raw materials and ships to transport them kept the mills operating even during the period of the French and Indian Wars when the mills were repeatedly targeted and burned. In 1679 Wells exported boards, shingles, and hoops. In 1790 a vessel of 800 tons was built along the banks of the Webhannet. By 1850 there were 24 registered shipwrights using local materials, and 132 ocean going ships were built between 1800 and 1884 (Shelley 2002).

European agriculture and settlement resembled that of the Native Americans at first with minimal impacts on the land and in the sea. Practices changed with the arrival and proliferation of livestock and the steadily increasing number of settlers. Due to the scarcity of labor and materials, livestock were allowed to roam freely and spent much time in the lush grasslands of the marshes. This grazing conflicted with the use of the marshes as a source of winter feed (hay) and food (shellfish) (Cronon 1983).

By 1757 damage had occurred to such an extent that livestock were banned from all tidal marshes by the Massachusetts Court, which included Maine in its jurisdiction. The law was revised with stricter penalties and enforcers were hired in 1827. In the 1890's, in order to increase hay supplies, a plan was drawn up and implemented to convert portions of the salt marsh to upland pasture through diking, draining, plowing, and planting of herd grass. The grass grew well but proved to be unpalatable to cattle. Active management was abandoned after a few years, but the modifications remained (Shelley 2002).

Local agriculture declined in the period following the Civil War and tourism first appeared as "farm stays" and grew to include cottages on the beaches. The railroad arrived in 1842, followed by local trolleys in the early 1900's. Ease of transportation greatly enhanced visitor access from both Boston and inland communities such as Dover and Sanford. Roads were improved and bridges were constructed over rivers with the arrival of the automobile.

As land transportation improved, the center of town activities migrated away from the harbor and marshes to the train station, US Route 1, and the beaches. In 1905 the Alice S. Wentworth, a coastal schooner, was the last to be built in Wells, ending the shipbuilding era. With this change the salt marshes surrounding the Webhannet and Little Rivers began to recover. This natural restoration continued up until the 1960's with the initial construction of the harbor and jetties, followed in the 1980's and 90's with a real estate market demand for ocean,, marsh, and river-front properties. This was followed by the re-development of small seasonal cottages into larger year-round homes.

The population of Wells was 4,489 in 1830. One hundred years later, it had contracted to less than half (1,948). By 1970 the number of residents had almost reached what it had been 160 years earlier (4,448). The growth that had been gradual up until 1970 began to accelerate, reaching 8,211 residents in 1980 and an estimated 10,240 (with a seasonal capacity of an additional 24,560 people) in 2004, even with the separation of the Village of Ogunquit (1,100 year round residents) as its own town in 1981.

Over the past 25 years, housing growth has been double the growth in population. In the decade of the 90's, population in Wells increased 20.9% while housing units grew by 49.4%. Much of this development has occurred in the Webhannet watershed between the Gulf of Maine and Interstate 95. This pattern of development is similar to that of surrounding coastal communities. (SMRPC 2006).

Currently, Wells is approximately 25% developed with another 10% of the land in conservation, leaving 65% undeveloped and available. Wetlands, slopes, and poor soils makes a portion of the remaining land unsuitable for construction and septic systems but there remains enough to double both the year round and seasonal populations. Growth pressure continues to increase extending northward from the metropolitan Boston area. In the decade of the 1990's Maine ranked 47th in the nation in population growth, in the first half of this decade it ranks 27th.

PUBLIC WATER SUPPLY

Branch Brook, a tributary to the Little River, has been a source of water for distribution since the late 1800's. It started with the Mousam Water Company serving summer residences along the beaches. First there was the private Mousam Water Company which was replaced by the York County Water Company. This company in

Aerial color-infrared photograph of the Webhannet River inlet showing beach, beach development, jetties, Wells harbor, filled marsh, natural marsh, and estuarine channels. Photo Wells NERR.

turn was replaced in 1921 with the establishment of the Kennebunk, Kennebunkport, and Wells Water District, a quasi-municipal water utility.

In 1980 peak demand was up to 4 million gallons per day (MGD) and exceeded the capacity of Branch Brook. By 2002 demand rose to 7 MGD servicing 28,000 year round and 75,000 seasonally, necessitating pipe connections with Biddeford (Saco River) and York (Chases Pond) to maintain supply. Demand is predicted to rise to 9 MGD by 2020 and eventually peak at 20 MGD with anticipated build out.

An expansion of capacity is currently under way (2006) with three groundwater wells being placed in the Branch Brook watershed and one in the Merriland River watershed with 3 MGD potential. A new treatment facility is also currently under construction (2006). Future plans include the continued linkage with other water districts (Portland and Kittery) and the possibility of moving toward desalinization technology.

LAND CONSERVATION

Permanent land conservation within the watersheds of Wells NERR began in 1966 with the establishment of the Coastal Maine National Wildlife Refuge, which was renamed in honor of Rachel Carson in 1969. The Refuge includes coastal land and marshes from Kittery to Cape Elizabeth. In 1971 the State of Maine acquired a portion (61 ha / 150 acres) of Laudholm Farm straddling the high ground between the estuaries of the Little and Webhannet rivers. This acquisition included 518 meters (1,700 ft) of beach (Laudholm Beach) for the future creation of a state park.

In the early 1980's the remaining 113 ha (280 acres) of Laudholm Farm came on the market, and a grassroots effort in the form of the Laudholm Trust was successful in purchasing the property by matching local donations with federal funds. This purchase created the Wells National Estuarine Research Reserve in 1986. By 2006 the Reserve boundaries comprised 907 ha (2,241 acres) through inclusion of the State land—the state park was never constructed—and 578 ha (1,428 acres) of adjacent Rachel Carson Wildlife Refuge lands (Wells NERR, in press).

Other efforts in the past 20 years have added to conservation within the watersheds of the Reserve. The Town of Wells through the efforts of its Conservation Commission has been securing land in the headwaters of both the Merriland and Webhannet rivers. The Fenderson Commons on the western edge of town (Merriland River) currently consists of 236 ha (582 acres) (2006). The Heath in the headwaters of the Webhannet includes 157 ha (388 acres) acquired by the town. The Conservation Commission is continuing its efforts to expanded these protected areas.

The Kennebunk, Kennebunkport, and Wells Water District (KK&W) uses Branch Brook as a surface water source for a portion of its water supply to approximately 3200 customers. To protect water quality in Branch Brook it has acquired 958 ha (2,368 acres) in the towns of Wells, Kennebunk, and Sanford, with 299 of those ha (739 acres) within Wells. This effort has kept impacts from development low in Branch Brook and subsequently in the Little River that flows through the Reserve.

Local land trusts and the Nature Conservancy have also been active in the watersheds. As of 2006, the Nature Conservancy in partnership with the State of Maine has protected 917 ha (2,266 acres) in the Kennebunk Plains area including a portion of the headwaters for Branch Brook. The Great Works Regional Land Trust has completed 2 projects protecting 134 ha (331 acres) through conservation easements within the watersheds of the Little and Webhannet Rivers.

Researchers examine rapid and severe erosion on conservation land near McGuire Road, in Kennebunk, in the Branch Brook watershed. Motorized vehicles cut through the thin topsoil exposing highly erodable sand. Photo Wells NERR.

The future for land conservation in the watersheds is faced with several opportunities and challenges. The land trusts, Wells Conservation Commission, and the Nature Conservancy have gained considerable experience and capacity over the past 20 years. The public and town officials have become more aware and knowledgeable about conservation options and are likely to continue their financial support. Land prices however have been rising dramatically (over 300% increase for house lot between 1999-2006) and even more so for land with proximity to water.

Dredge equipment in the Webhannet Harbor, year 2000. Photo Susan Bickford.

The KK&W Water District is experiencing increasing demands for water – particularly in summer – while Branch Brook remains a limited source even with four new wells in 2006. Future plans include the possibility of moving toward desalinization technology which could require the selling of the District lands (958 ha / 2368 acres) to finance the facility and equipment. The development of a significant portion of those properties would likely have a negative effect on the Little River Estuary.

The management of protected lands is another challenge. All of the conservation land owners, including the towns, and the Water District experience public use of their lands that require resources—money and staff—to manage. The resources needed to manage sites are often inadequate. The most noticeable problem is with "off-road" vehicle use in the Kennebunk Plains section of the Branch Brook watershed (see photo). A large amount of conserved, and thus open, land is available. The area has a thin layer of topsoil on a sandy substrate with areas of moderate to steep slopes. Frequent vehicle use has removed the vegetated top layer on regularly used trails and this in conjunction with precipitation has resulted in areas of spectacular erosion. When erosion becomes so severe as to impede off-road vehicle use, a new trail is started.

The Estuaries

The tidal portion of the Little River Estuary (202 ha / 500 acres) exhibits little evidence of human impact except for some ditching and diking most likely from the 1890's and 1930's. It was likely too small and inaccessible to have been regularly used for sea transport during the first two centuries of European settlement but was used for animal grazing and the harvesting of hay. The salt marsh is currently owned by the Rachel Carson National Wildlife Refuge. The surrounding upland is lightly developed with the northwest, west and southwest sides owned by the Wells NERR or the Refuge. Crescent Surf Beach and its adjacent upland on the north and northeast side remains in private ownership and has seen some development in the past 5 years.

The Webhannet Estuary absorbed far greater impacts from European settlement. The estuary and immediately adjacent uplands recovered during the early to mid 20th century from the intensive use of the previous two hundred years. However, development since the 1960's has included the dredging and re-dredging of the harbor and river channel with construction of the jetties, development of surrounding fields and wooded areas along the marsh edge to high density commercial and residential use, and the conversion of seasonal cottages on the beach strand to year round and increasingly larger homes.

Between 1961 and 1974, under the direction of the Army Corps of Engineers and paid for largely by federal funds, 382,000 cubic meters of sand was dredged to create a channel and anchorage. The dredged spoil was placed on the adjacent salt marsh creating 17.4 ha (43 acres) of upland area. A restaurant and marina were constructed there along with boat trailer access, a wharf, and parking. A park with a gazebo, sheltered tables, playground, and viewing platform were added after a plan to develop a shopping and convention center was rejected by town voters.

The jetty and subsequent efforts to manage and maintain the harbor have impacted both the tidal flow of the estuary and the movement of sand along the barrier beaches. Flood tidal currents and volume are significantly higher due to the jetties and dredged channel. Sand movement north and south along the barrier beach has been interrupted by the jetties as well.

The 1974 dredging established 186 anchorages but six years later only 40 of those anchorages were still useable as higher than predicted amounts of sand were carried in and trapped in the mooring basin. The rapid infilling has been blamed on the design of the jetties that face almost directly into the prevailing storm waves and the boat anchorage serving as a settling basin for sediment carrying currents. In addition to sand being trapped in the harbor, more than 76,040 cubic meters of sand by the year 2000 had accumulated on the beach sides of the jetties while erosion noticeably accelerated along both Wells and Drakes Island beaches. This erosion has exposed cobble and ledge outcrops, threatening houses and seawalls with direct wave impacts in storms.

After more than a decade of public discourse the harbor and channel were re-dredged in 2000-2001 with the sand placed onto both the Wells and Drakes Island beaches (see photo). This dredge is currently being monitored for its impacts on the beaches, harbor, and the salt marsh. By 2005 the harbor was again losing anchorages and it was difficult to see evidence of the sand that had been placed on the beaches. The question has once again surfaced for public debate: whether a functioning harbor and beaches attractive to seasonal residents can co-exist at a reasonable cost. The Webhannet Estuary and associated Wells and Drakes Island beaches are expected to continue to be dynamic systems.

REFERENCES

Cronon, William. 1983. Changes in the land : Indians, colonists, and the ecology of New England. Hill and Wang New York, NY 241pp

Shelley, H. M. 2002 My name is Wells : I am the town : a history of the town of Wells, Maine on the occasion of its 350th anniversary of incorporation. Penobscot Press, Rockport, ME. 355 pp.

Smith, M. 2003a. Watershed conservation strategies: Webhannet River watershed. Wells National Estuarine Research Reserve, Wells, ME. 25 pp.

Smith, M. 2003b. Watershed conservation strategies: Merriland River, Branch Brook, and Little River (MBLR) watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. and H. True. 2004. Merriland River, Branch Brook, and Little River (MBLR) watershed nonpoint source pollution management plan. Wells National Estuarine Research Reserve, Wells, ME. 48 pp.

Southern Maine Regional Planning Commission. 2004. Census data available at http://www.smrpc.org/census/PopulationEstimates2004.pdf

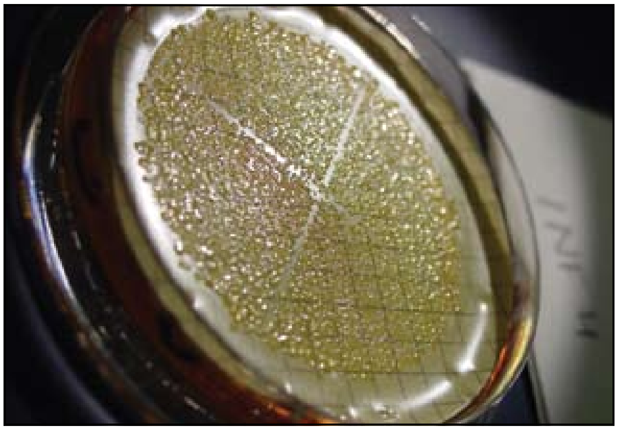
Wells National Estuarine Research Reserve. *In press.* Reserve Management Plan. Wells National Estuarine Research Reserve, Wells, ME.

Chapter 6

Water Quality

Christopher Cayce Dalton

Water quality at Wells NERR is generally good,. since the industrial pressures so common to other New England estuaries have historically been absent, and coastal development is moderate compared to the southern New England coast. Despite a history that has substantially protected water quality, development pressures have dramatically accelerated in the past few decades. Currently, water quality concerns focus on bacterial concentrations, which threaten the recreational shellfish harvest in the Webhannet River, and the summer tourist economy, which depends heavily on beaches for swimming, kayaking and other water-contact activities.



E. coli bacteria on a membrane filter, a common indicator of water quality. Photo Cayce Dalton.

Regional Setting

The water quality of Wells NERR estuaries is strongly influenced by their location at the western shore of the Gulf of Maine. This semi-enclosed sea is one of the world's most productive marine zones, characterized by well-mixed, nutrient-rich waters. Typically, currents move in a counter-clockwise direction, so that southern Maine coastal waters usually consist of frigid currents that have entered the Gulf a few months earlier through the Northeast Channel south of Nova Scotia, and have swept in a southeastern direction past New Brunswick and eastern Maine. Occasionally, this flow is altered when an eddy called a "warm-core ring" injects subtropical water and fish into the Gulf of Maine from south of Cape Cod, augmenting the ecological diversity of the region. (Tyrrell 2005)

Recently, heavy development pressure has been felt in southern Maine, with construction of new homes, condominiums and high-density vacation complexes a regular sight in coastal York County. The county population increased far above the state average during the 1990's (13.4% compared to 3.8%) (Whiting-Grant *et al.* 2003, US Census Bureau 2003). Population density of year-round residents reaches into the thousands per square mile in certain areas around Wells NERR, and

A view of Drakes Island Marsh in the Webhannet Estuary, where high bacterial counts have closed portions of the Webhannet Estuary to clamming. Photo Cayce Dalton.

the seasonal population of the town of Wells more than triples in the summer to about 34,000 (NOAA Coastal Services Center 2005). Daytime traffic on US Route 1 during July and August is extremely heavy, often slowing to a crawl for hours at a time. The clusters of high-density development, seasonal traffic saturation, and a steady pace of new construction are signs of human influences from watershed on the estuaries of Wells NERR.

LOCAL SETTING

Despite sharing the regional context described above, there are several key differences between the two estuaries encompassed by Wells NERR. The Webhannet Estuary is ringed by dense commercial and residential development, most of it showing a strong seasonal pattern of activity. Many hotels, restaurants and campgrounds overlook the estuary and the lower portion of its tributaries. Supermarkets, filling stations, banks and other basic service and retail activities are also within a few hundred meters of the marsh edge. The watershed's small size (about 25 km^2) and small freshwater inflow, combined with the fact that the tidal range is so large that most of the estuary's mud floor is exposed during low tide, result in a highly tidally flushed water column, with near marine salinities at high tide. The Webhannet is considered less susceptible to land-based influences than nearby estuaries with larger watersheds and higher freshwater inflow.

By contrast, the Merriland River, Branch Brook, and Little River (MBLR) watershed encompasses 81 km^2, has higher fresh water inflow and a smaller marsh than the Webhannet. As a result, salinities in the estuary are lower, and the influence of marine waters relative to freshwater is lower, indicating an estuary that is geomorphically more susceptible to pollutants from the watershed (Smith and True 2004), although still well flushed by national standards (Bricker *et al.* 2006). Land cover in the MBLR watershed is predominately forest. Due to sparse development and significant land conservation, anthropogenic pressures on the MBLR are low.

STATE CLASSIFICATION OF WATERS AT WELLS NERR

The state of Maine classifies surface waters according to water quality goals in order to focus management at the state level (Maine DEP 1999). The classification is best described as a hierarchy of priorities rather than of use or quality. It is ultimately aimed at meeting the federal Clean Water Act's minimum fishable-swimmable standards.

There are four classes of freshwater streams according to MRSA. The following is a greatly abbreviated summary of these definitions (MRSA, Title 38, Chapter 3, § 465):

- ◊ Class AA: outstanding natural resources meriting preservation because of ecological, social, scenic or recreational importance; no direct discharge of pollutants; dissolved oxygen and bacterial as naturally occurs; habitat characterized as free-flowing and natural.
- ◊ Class A: dissolved oxygen not less than 7 ppm or 75% natural saturation, whichever is higher, aquatic life and bacteria as naturally occurs; habitat characterized as natural.
- ◊ Class B: dissolved oxygen goals are seasonal; *E. coli* geometric mean less than 64 per 100mL and instantaneous samples less than 236 per 100mL; habitat characterized as unimpaired.
- ◊ Class C: dissolved oxygen goal is 30 day average; *E. coli* geometric mean less than 126 per 100mL; some discharges allowed although habitat should support all indigenous fish species.

The above freshwater quality standards have been applied to Wells NERR watershed as follows (MRSA, Title 38, Chapter 3, § 468): the following freshwater tributaries to the Webhannet are class A: the Webhannet River above US Route 1, Depot Brook and Blacksmith Brook above US Route 1. All other tributaries (Popes Creek, Webhannet River below US Route 1 and Blacksmith Brook below US Route 1) are class B. Both Branch Brook and the Merriland River are class A.

There are three classes of estuarine and marine waters, summarized as follows (MRSA, Title 38, Chapter 3, § 465-B):

- ◊ Class SA: outstanding natural resources meriting preservation because of ecological, social, scenic or recreational importance; dissolved oxygen and bacteria as naturally occurs; only approved storm water discharges allowed.
- ◊ Class SB: dissolved oxygen concentrations at least 85% of saturation; summer seasonal enterococcus geometric mean not greater than 8 per 100mL and instantaneous limit of 54 per 100mL.
- ◊ Class SC: dissolved oxygen concentrations at least 70% of saturation; spring and summer seasonal enterococcus geometric mean not greater than 14 per 100mL and instantaneous limit of 94 per 100mL.

The above estuarine standards have been applied to Wells NERR watershed as follows (MRSA, Title 38, Chapter 3, § 469): Merriland / Branch Brook / Little River (MBLR) estuarine waters are classified as SA, and the Webhannet's as SB.

In addition, the state of Maine has created a priority designation for some water bodies. The Webhannet Estuary is listed as a priority coastal water body due to the threat from bacteria and low dissolved oxygen and its high resource value. Branch Brook was listed as a priority river by Maine DEP in 1998 due to threat of non-point source pollution and its use as a drinking water supply for the area. This designation helps obtain preferential treatment by state agencies for these estuaries, including qualifying for additional funding sources (Maine DEP 2004).

HEAVY METALS AND TOXINS

Maine has been called the "tailpipe of the nation" as a result of its geographic position downwind from two major industrial regions, the Eastern Seaboard and the Midwest. Despite having relatively sparse population and few sources of industrial air pollution in the state, Maine nonetheless suffers pollution from such sources.

The region surrounding Wells NERR was primarily a sparsely populated agricultural community until the late 1800's when tourism became an important economic activity in the region (Sebold 1998). The small estuaries of Wells NERR did not find themselves adjacent to the heavy industrial development which characterized more urban areas of northern New England, thus generally avoiding a history of associated toxic contamination. Perhaps as a result of this non-industrial history, few studies have focused on toxic contamination specifically in Wells NERR estuaries.

Metals in Marsh Sediments as Indicator of Water Quality Trends

Sediment cores from the Webhannet marsh indicate that copper and manganese in sediments occurs at natural levels. Peaks in zinc concentrations occurred well before significant European settlement in the area, and are not considered anthropogenic in source. In fact, zinc levels in recent sediments have been very low. Zinc often is associated with heavy industry, which has been absent in the watershed. (Canfield 2000).

Recent sediments were found to be enriched in lead from about the time of the industrial revolution, peaking about the 1920's. Canfield (2000) offers two plausible explanations for this early lead enrichment. It could be due to atmospheric deposition from distant industrial sources, since automobiles were uncommon in the area at that time and no heavy industry was located near the estuary. Alternatively, it could have arrived via lead contaminated wastewater releases from the increasing population in the watershed from the 1930's. Other more recent sources are likely to be road runoff, since Interstate 95 and State Route 9 both pass through the upper portion of the watershed, and the town of Wells has virtually no stormwater collection system. Lead concentrations have declined from about 1970 to the present. This decline may be due to national legislation which eliminated lead in gasoline, and the installation of a wastewater treatment facility in Wells in 1980 that discharges to offshore waters. Lead levels in most recent sediments are about six times the late 1800's levels, but about one third of peak levels (Canfield 2000).

Very Low Levels of PAH's found in Webhannet Marsh Sediments

Another potential estuarine contaminant is the group of chemicals known as polycyclic aromatic hydrocarbons (PAH's). These substances are produced by incomplete combustion of coal, oil, gas, wood, garbage, or other organic substances, and are associated with an increased risk of cancer. Most do not dissolve readily in water, but do attach to soil particles (ATSDR 1995). A recent study focusing on remediation of PAH's in estuaries around the country included repeated extraction tests of sediments from the Webhannet Estuary (A. Hong, personal communication). Levels were found to be among the lowest among all sample tested from around the country at 3.90 ppm (std dev = 0.01) most of which were 3-ring compounds with few 4- or 5-ring compounds. Other NERRs showed levels as high as 800 ppm. Levels in the Webhannet Estuary were too low to merit application of the remediation techniques proposed by Hong. These results, though not comprehensive, do provide some evidence that PAH contamination at Wells NERR is very low.

Blue Mussels in the Area Show Low Levels of Toxic Contaminants

The common blue mussel, *Mytilus edulis*, has been used to assess toxic contamination extensively around the world. These filter feeders integrate toxins into their tissues over periods of weeks and months, revealing average conditions of biologically available contaminants across a medium-term time frame. Maine DEP has tested mussel tissues for over a decade all along the coast of Maine. Contamination has been highest in areas where industry and population have concentrated, such as Portland and Rockland, and generally low elsewhere (Maine DEP, undated).

Mussel tissues from Brave Boat Harbor (26 km to southwest) were sampled in 1989, 1993 and 1996 and showed generally low levels of a suite of metals (silver, cadmium, chromium, copper, lead, mercury, nickel, aluminum and iron). Cape Neddick (17 km to the southwest) also showed generally low levels of metals, only zinc being slightly above the normal range. These tissues were sampled only on one date in 1992 (Maine DEP, undated).

Atmospheric Mercury Deposition is a Region-wide Risk

Elemental mercury is deposited to land and water throughout Maine, and is subsequently converted by bacteria to the highly toxic methylmercury. Levels of mercury in Maine fish are among the highest in North America, and a fish consumption advisory has been in effect in Maine since 1994. Mercury has been found in levels that would compromise fetal development in 10-20% of women of childbearing age in Maine. Significant reductions in mercury emission in-state have occurred, due to federal regulation of large municipal waste incinerators in 2000, state regulation of other point sources of mercury in 2000 and 2004, and the closure in 2000 of HoltraChem which was New England's only mercury cell chlor-alkali production facility. With these improvements, industrial and utility boilers have become the largest in-state sources of mercury. About 30% of mercury deposited in New England comes from outside the region. (Maine DEP 2002).

In Maine, the highest rates of deposition were found at Freeport (70 km to northeast) and Acadia (210 km to northeast), with somewhat lower levels in Bridgton (84 km to north) and Greenville (251 km to north) (Maine DEP 2002). Total annual wet deposition of mercury in Freeport, Maine (Wolfe's Neck Farm, site ME96, 70 km to northeast of Wells NERR) from 2000 to 2004 ranged from 4.9 to 10.2 $\mu g\ m^{-2}$. In Maine, from 1998 through 2004, with the exception of 2003, higher rates of wet deposition were found at coastal sites such as Freeport than at inland sites such as Bridgton and Greenville (Mercury Deposition Network 2006). Atmospheric deposition was found to be the dominant source (84 to 92% of total) to Casco Bay (Ryan *et al.* 2003). Data for the Webhannet Estuary indicate very low levels of mercury, despite the vicinity to Casco Bay and the fact that regional atmospheric sources are probably similar (Chen *et al.* 2004).

Dioxin and Furan in Fish Tissues as Indicator of Water Quality

Dioxin and furan concentrations in fish tissue in Maine have been declining, although they remain high enough in some areas to warrant fish consumption advisories. Although no information is available specific to Wells NERR, other rivers in Maine such as the Penobscot (approximately 190 km to northeast), the Kennebec (approximately 85 km to the northeast) and the Salmon Falls (approximately 22 km to west) are monitored. A fish tissue action level (FTAL) has been established by the Maine Bureau of Health, currently 1.5 parts per trillion (ppt). A proposed level of 0.4 ppt is being considered. In the Penobscot and Kennebec rivers, smallmouth bass and brown trout both showed levels below current and proposed FTAL, while levels in white suckers (see photo) were below the current FTAL but above the proposed level. In the Salmon Falls River as well, bass and sucker show levels below both the current and proposed FTAL (Maine DEP 2004). Given the historical absence of industries that generate dioxins and furan in the watersheds of Wells NERR, levels are likely at or below those found in these nearby rivers.

For white sucker in the Penobscot and Kennebec rivers, levels of dioxin and furan were found to be above the proposed federal fish tissuse actions level (FTAL). Photo Jim Dochtermann.

MTBE, an additive that replaced lead in gasoline, has been identified as a groundwater pollutant in the state of Maine. This toxic chemical makes up about 3% of gasoline. It makes up 11% of reformulated gasoline, but Maine has not participated in the reformulated gasoline program since March of 1999. Increasing concern about this pollutant led to a statewide study in 1998 which revealed that about 16% of wells and public water supplies showed detectable traces of MTBE, while no public water supplies and 1% of private wells showed levels above the maximum contaminant level (MCL). The chemical was detected broadly across the state, not only in areas where reformulated gasoline was sold. A study by the US Geological Survey (USGS) and the Maine DEP in Windham, Maine, concluded that the atmospheric deposition was unlikely to be a significant source, and instead small scale spills associated with recreational vehicles and lawn care equipment are the most likely sources. (Maine DEP 2004). No detailed study of MTBE has been conducted in Wells NERR watersheds.

BACTERIAL CONTAMINATION

Elevated levels of fecal-related bacteria have been recorded in parts of both the Webhannet and MBLR watersheds for many years (Bright 1996, Wells NERR 2001, Whiting-Grant *et al.* 2003 and 2004). In 1969, all shellfish harvesting areas in the Webhannet Estuary

Researcher Fred Dillon collects muscrat scat for the Microbial Source Tracking Program conducted at Wells NERR 2001-2004. Samples from suspected sources of bacteria in the watershed were genetically analyzed and compared to those of bacterial in the water. Photo Cayce Dalton.

were closed due to contamination (Canfield 2000). Bacteria of this type indicate a risk of gastrointestinal and other diseases from consuming raw shellfish, and ear and eye infections among other diseases from water contact. Because potential pathogens associated with fecal contamination are highly varied (and they may occur in very low concentrations and are difficult to detect directly) benign indicator organisms are typically used as a measure of the likely presence of disease vectors. At least three different indicators are used in Maine to measure this risk. The Maine Department of Environmental Protection (DEP) uses *E. coli* in freshwater streams, the Maine Department of Marine Resources (DMR) uses fecal coliform for shellfish harvesting standards, and the Maine Healthy Beaches Program uses enterococci for swim beach monitoring.

MRSA set bacterial concentrations for shellfish harvesting areas according to National Shellfish Sanitation Program Model Ordinance (USFDA, 2000). Maine Department of Marine Resources (DMR) analyzes 6 to 12 samples per year using a "most probable number" (MPN) method at coastal and estuarine sites, and uses the most recent 30 samples (spanning 2.5 to 5 years) in order to determine shellfish harvesting status. The geometric mean cannot exceed 14 MPN per 100 mL, and the 90th percentile cannot exceed 49 MPN per 100 mL. Areas exceeding this concentration are closed to general shellfish harvesting. If the 90th percentile is less than 88 MPN per 100 mL, the area can be classified as restricted,

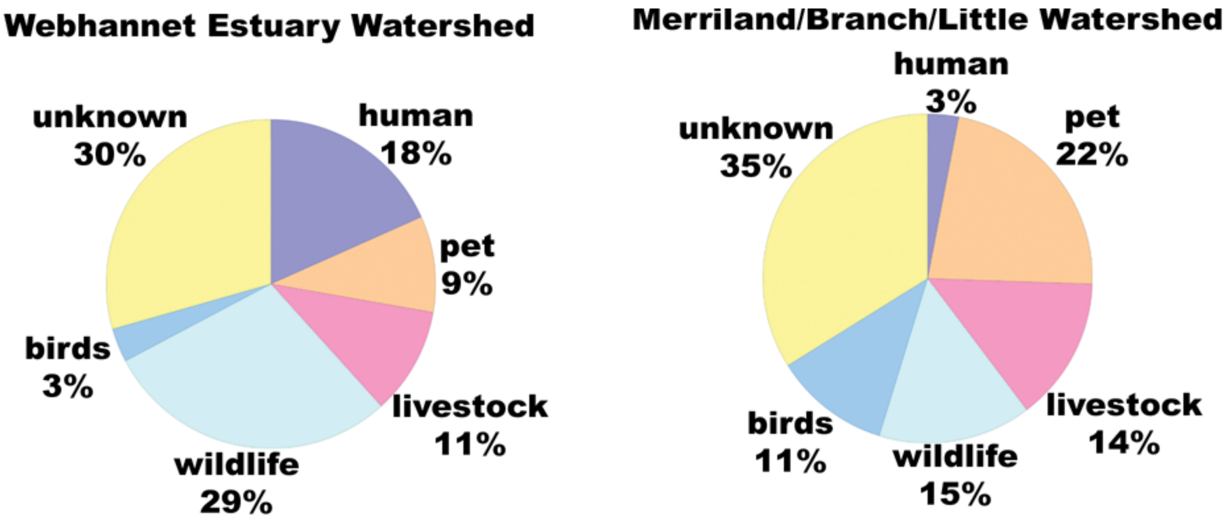


Figure 6-2: Bacterial sources identified by category in the Microbial Source Tracking Project. The Webhannet watershed was studied for a one year period in 2001-2002 and the MBLR watershed the following year.

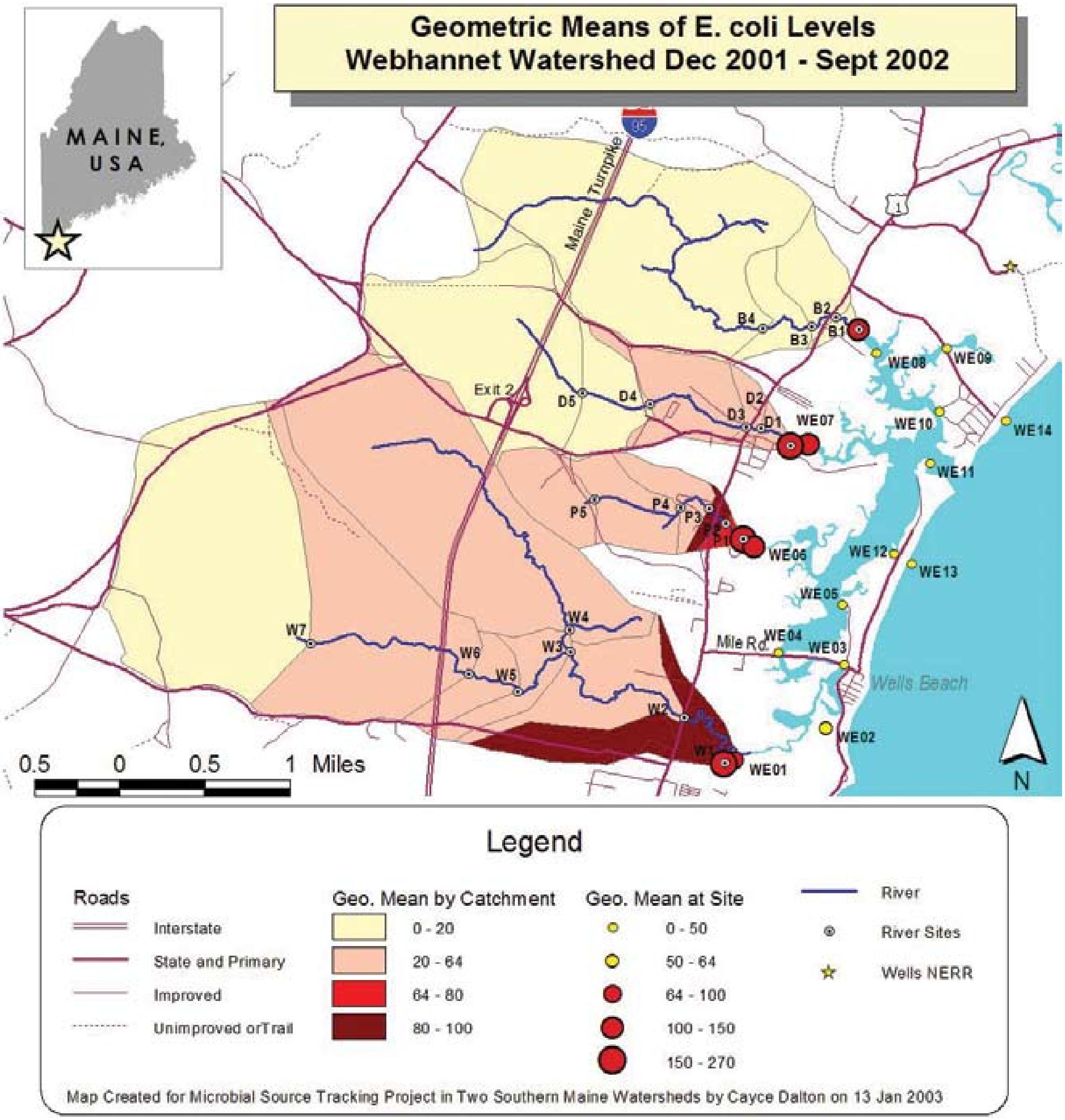


Figure 6-1: Map showing geometric means of *E. coli* bacteria in the Webhannet watershed in 2001-2002. Highest levels were found in the Route 1 corridor and at the head of tide of tributary streams. Map Cayce Dalton.

meaning shellfish can be harvested but must undergo depuration in clean water before being consumed. In cases where the 90th percentile exceeds 88 MPN per 100 mL, shellfish harvesting is prohibited (Whiting-Grant *et al.* 2003).

The town of Wells has a relatively modern wastewater treatment plant, completed in 1980. Due to overloading by an increasing seasonal population, it underwent a series of upgrades and enhancements in 2002. Wastewater influent is not seen to increase significantly during precipitation events, which is considered a sign that the system is not particularly prone to leaks as many older systems are (Whiting-Grant *et al.* 2003). This system is not thought to be a major source of bacterial contamination to the watershed.

Regular fecal coliform sampling and sanitary surveys in the 1990's resulted in a better understanding of where and when bacterial levels are elevated, and enabled the partial re-opening of clam beds in the Webhannet Estuary (once known as the clam capital of Maine) in 1996 and an additional area in Pope's Creek in 2000. Testing identified the freshwater tributaries as the primary channel through which bacteria enter the estuary (Wells NERR 2001, Whiting-Grant *et al.* 2003 and 2004). Additional sanitary surveys in the Webhannet watershed were conducted in 2000 and 2002 (Wells NERR 2001, Kristen Whiting-Grant *et al.* 2003). In general, these surveys identified the three southernmost tributaries as the principle sources of bacteria to the estuary: Depot Brook, Popes Creek and the Webhannet River. In addition to anthropogenic sources, wildlife sources such as otter, beaver, deer and ducks were noted as likely contributors. Wells Harbor was generally found to have low bacterial concentrations, likely due to highly flushed nature of the estuary's main channel.

A project using microbial source tracking techniques investigated bacterial contamination in Wells NERR watersheds from 2001 to 2003. The goal of this project was to overcome one of the primary limitations of conventional bacterial testing, the absence of any indication of source. Genetic analysis (ribotyping) of bacteria both from the watershed and from suspected source species was carried out. The project used membrane filtration to test both for fecal coliform and *E. coli* concentrations, expressed as colony forming units (CFU) per 100 mL.

Sampling occurred in the freshwater portion of the Webhannet watershed during the winter, which corresponded to the recreational clam harvesting season, while estuarine sampling occurred in the summer. This project confirmed prior findings that bacteria enter the Webhannet Estuary via tributary streams, and found highest concentrations (geometric mean > 100 CFU) in the most densely developed portion of the watershed between US Route 1 and the estuary. Inland areas showed lower bacterial concentrations (geometric means < 64 CFU), within the Maine DEP seasonal limit for class B streams, with results showing high variability. In the estuary, geometric means were generally low as well (Fig. 6-1), although Maine Department of Marine Resources (DMR) has found elevated levels in the southern third of the estuary and as a result has restricted shellfish harvesting south of Mile Road. Elevated bacteria concentrations were sometimes, but not always, associated with precipitation events. Maine DMR testing has indicated generally low bacterial levels in stormwater runoff (Whiting-Grant *et al.* 2003).

High discharge during and after high precipitation events, as seen here where the Merriland River flows into the Little River estuary, delivers non-point source pollutants to the Reserve's estuaries. Photo Jeremy Miller.

While elevated levels of *E. coli* were found in tributaries of the Webhannet estuary, summer testing by the Maine Healthy Beaches Program for entercocci of coastal waters just outside the estuary has shown generally low levels of bacteria. The geometric mean of these coastal waters was well below the EPA limit of 35, usually between 5 and 10 (Maine Healthy Beaches Program 2006).

The genetic analysis of bacteria was based on matching the rRNA ribotypes of bacteria isolated from water samples to those isolated directly from fecal samples of suspected sources, including human, pet, livestock and wildlife species. The single largest identified source was human (18%). Looking at categories of sources, the largest category was human-related (pets, livestock and human) at 38%, followed by wildlife at 29%. For 30% of samples, the analysis did not identify a source (Fig. 6-2; Whiting-Grant *et al.* 2003).

A shoreline survey in the MBLR watershed conducted by Wells NERR researchers in 2001 revealed relatively few probable sources of bacterial contamination. An additional survey in 2003 focusing on areas more inland found potential sources of bacterial contamination in the MBLR watershed to be primarily livestock (horses, cows and ducks). The Kennebunk, Kennebunkport, Wells Water District added that according to their annual surveys of the drinking water portion of the watershed, wildlife and dogs were likely contributors (Whiting-Grant *et al.* 2004).

In general, bacterial concentrations were low over the sample period in the MBLR watershed, with the maximum geometric mean at any site just 31.7 CFU. The sampling period was from early December to late May, and included a mix of dry and post-precipitation sampling. Colder than normal conditions with less than normal precipitation may have reduced the representativeness of these samples. In late May, bacterial concentrations rose considerably, and since no summer sampling was conducted due to time constraints it is not possible to compare the two watersheds based on this sampling alone. No apparent relationship was observed between precipitation and bacterial concentrations. The Merriland River showed higher bacterial concentrations than Branch Brook, although geometric means were in general low in both watersheds.

Despite these low bacterial concentrations, DMR sampling indicates fecal coliform levels regularly exceeded the standard for shellfish harvesting at their site D25 located near the head of tide in the estuarine portion of Branch Brook from 1998-2003, while site D27 near the mouth of the estuary has met the standard in recent years (2000-2003). Since 2000, DMR has modified its sampling schedule so that only winter samples are taken, since this is when a potential shellfish harvesting season would be opened. The lower wintertime concentrations found by DMR confirm the low wintertime bacterial concentrations found by the Microbial Source Tracking project.

Results of genetic analysis in the MBLR watershed were strikingly different than those in the Webhannet. The most frequently identified sources were cats (21%), followed by cow (11%). The analysis was inconclusive for 35% of samples. Looking at general categories, pet and livestock together totaled 36%, wildlife was 15%, while human sources were only 3%. The high percentage from cats was considered a possible consequence of dumping of kitty litter near waterways (Whiting-Grant *et al.* 2004). Dumping of cat waste is alluded to in the 1996 Sanitary Survey of the Webhannet watershed in the Depot Brook area, although it apparently had ceased by that time (Bright 1996).

NUTRIENTS AND DISSOLVED OXYGEN

Many studies have been conducted in recent years on nutrients and associated topics at Wells NERR. The Webhannet and MBLR estuaries are not generally considered to suffer from water quality degradation due to anthropogenic nutrient enrichment, a condition known as eutrophication. Nitrogen appears to be the limiting nutrient in the Webhannet estuary according to the Redfield ratio (Holden 1997). This suggests increased nitrogen delivery to the estuary would stimulate excessive algal or phytoplankton growth, disturbing the ecological balance and potentially leading to more entrenched symptoms of eutrophication such as dissolved oxygen depletion. Oxygen depletion stresses or suffocates fish, shellfish and other marine organisms that require oxygen to live. Despite the fact that few signs of eutrophication have appeared at Wells NERR, extremely heavy coastal development in the town of Wells combined with a recently worsening pattern of hypoxia (and sometimes anoxia) at Wells Harbor are generating concern.

Several surveys of dissolved oxygen (DO) have been conducted over the past 15 years in and around Wells NERR. During the period May 1990 to June 1992, dissolved oxygen was measured both at Wells Harbor and at Mile Road (mid estuary). Levels were generally well above any problem threshold, although minimum values occasionally dipped into the biological stress range (< 5 mg/L). Only on two days during that period and only at Wells Harbor did DO fall below 3 mg/L, perhaps an early indication of some degree of susceptibility to low DO at that site (Ward 1993).

A survey of dissolved oxygen conditions in 1995 across the Gulf of Maine from New Hampshire to Canada was conducted and included the MBLR watershed (Kelly *et al.* 1996). This study was repeated and expanded to include nutrients, and covered more estuaries including the

Webhannet, the following year (Kelly 1997). Dissolved oxygen levels in Gulf of Maine estuaries in general were found to be high, only about 1.5% of all Maine samples were <5.5 mg/L, with lowest levels in September (rather than August as expected). Despite generally high levels in both the Webhannet and MBLR estuaries, they both were in the lower range for Maine estuaries, perhaps indicating a greater susceptibility on a regional level. Regarding nutrients, the Webhannet showed a mean DIN concentration of 2.2 μg/L, while the MBLR was about double that at 4.7 μg/L. Both of these concentrations are very low when compared to other estuaries around the nation (Kelly 1997).

Generally in the Gulf of Maine from New Hampshire to Canada, measures of nutrients including chlorophyll-a revealed levels well below those that would indicate eutrophic conditions. Together with ample dissolved oxygen, these data did not indicate cause for concern. The highly flushed nature of most Gulf of Maine estuaries due to large tidal range was cited as a factor that protected these estuaries from nutrient enrichment. Nonetheless, lower salinity was correlated with higher nutrients and lower dissolved oxygen, suggesting that the estuaries were not completely immune from land-based influences, and the MBLR watershed showed lower DO levels than other Maine estuaries (Kelly 1997).

Ward (2004) also considers the Webhannet to be highly flushed, and to benefit from ample dilution since the volume of freshwater inflow is only about 0.5% of the tidal prism. During rain events maximum salinities at several sample sites remained fairly high, again suggesting that the estuary is dominated by offshore waters.

The Assessment of Estuarine Trophic Status (ASSETS) is a method of measuring current and expected future eutrophication developed by NOAA. ASSETS has been applied at 157 estuaries around the world, and uses five common symptoms of eutrophication (chlorophyll-a, macroalgae blooms, dissolved oxygen depletion, hazardous or nuisanance algal blooms), combined with future nutrient trends. An application of the Assessment of Estuarine Trophic Status (ASSETS) methodology further indicates that relative to other estuaries around the country, the Webhannet receives a smaller portion of nitrogen nutrients from the watershed, and relatively more from offshore waters, which suggests that land-based nutrient sources are less important in the estuary (Bricker *et al.* 2006).

Low levels of the most typical symptoms of eutrophication are observed in the estuary: chlorophyll-a, macroalgae, submerged aquatic vegetation loss and hazardous or nuisance algal blooms. Only one symptom, dissolved oxygen, showed markedly worsening conditions at one sample station, Wells Harbor, during the second half of 2004. These conditions worsened further and became extremely persistent in 2005 and early 2006, manifesting steadily declining dissolved oxygen—frequently to the point of hypoxia and occasionally to anoxia—on the outgoing tide, rebounding quickly about two hours after low tide (Miller, personal communication; see Ch. 15). DO measurements from other studies in the Webhannet main channel (both surface and bottom) suggest these conditions occur only in the immediate vicinity of Wells Harbor. One plausible explanation would be dumping at the harbor of organic material with high biological oxygen demand such as unused bait or overboard discharge (septic waste) from boats anchored near the oxygen sensor, which is deployed near the bottom of a deep, dredged basin. If so it would not indicate a system-wide problem. Further investigation is needed to determine the spatial extent of these worrisome conditions.

Strong development pressures and increasing population in the Webhannet watershed are expected to increase nutrient pressures in the estuary. Holden (1997) indicated developed land covering 18.6% of the watershed, with about 10% being high density development. The town of Wells from 1990 to 2000 experienced a growth in year-round population of about 21%, rising from 7,778 to 9,400 (Southern Maine Regional Planning Commission, 2000). To what degree the seasonal population has increased is not precisely measured; however, it is suspected to have shown strong growth since many new developments near the shoreline are seasonal cottages.

The MBLR watershed's morphology is considered to make it more susceptible to nutrient enrichment, since it has a larger freshwater inflow and a smaller tidal prism. Fortunately, this higher susceptibility is probably offset by very low nutrient pressure, due primarily to low level of development in the watershed, between 3% (Whiting-

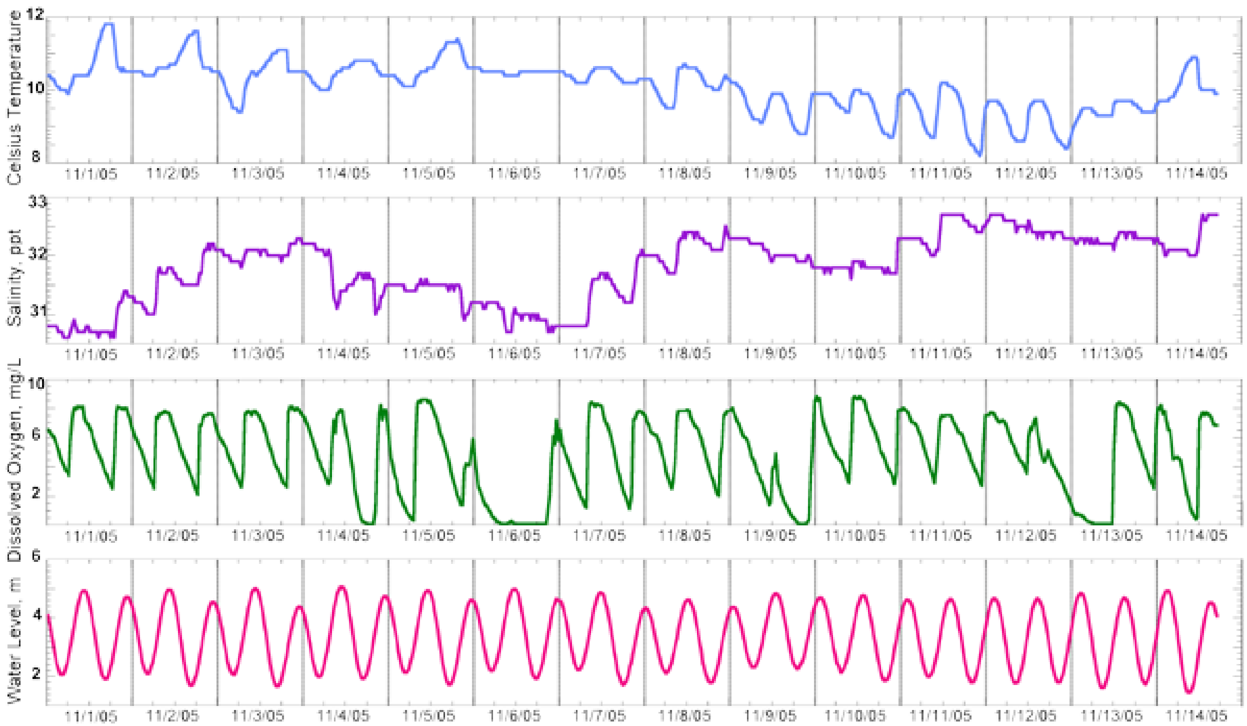


Figure 6-3: Water quality parameters for the Webhannet Inlet. Note the periodic dips in dissolved oxygen conentration. Data Wells NERR. Figure Hannah Wilhelm.

Grant *et al.* 2004) and 6% (Smith and True 2004). Using the ASSETS methodology, all symptoms of eutrophication are observed at the lowest levels (Bricker *et al.* 2006, Dalton *et al.* 2006).

Future nutrient pressures in the MBLR are expected to be moderated by the fact that a significant portion (about 21%) of the watershed benefits from *de facto* conservation (owned by the public water utility in an undeveloped condition, but without conservation easements). Only 3% of all land in the watershed is zoned for intensive use, and most of that is in the upper portion of the watershed in the town of Wells (Smith and True 2004). As a result, the estuary is considered at lower risk of eutrophication in the future, despite its relatively higher susceptibility.

Management Recommendations

Wells NERR is located on two small estuaries with a history of sparse settlement just beyond the edge of major urban centers such as Boston and coastal New Hampshire. Toxic contamination to estuarine waters appears limited to regional influences, such as atmospheric deposition of mercury and lead associated in large part with industrial and urban sources outside the watershed. In order to protect the waters from these threats, continued efforts on the state, regional and national level are necessary to reduce airborne contaminants that circulate freely across borders.

The natural setting roughly in the middle of the Gulf of Maine—renowned for cold, nutrient rich waters from the north Atlantic and very high tides—and the characteristics of shallow morphology and small freshwater inflow, appear to protect these estuaries from anthropogenic nutrient enrichment from the watershed. There does not appear to be a history of the classic symptoms of eutrophication such as nuisance algal blooms or widespread oxygen deficiencies. Nonetheless, the Webhannet and MBLR appear more susceptible to eutrophication than many other Gulf of Maine estuaries. The Webhannet in particular shows two warning signals that deserve close attention at this point: rapid and dense development near the shoreline and an unexplained pattern of hypoxia and anoxia at Wells Harbor. The MBLR, which is perhaps the more naturally sensitive estuary of the two due to its larger watershed, higher freshwater inflow, and lower tidal flushing has been protected by *de facto* land conservation around the local drinking water source, Branch Brook, and by the fact that it is between two villages and has seen a more gentle pattern of development.

Bacterial contamination has been present over the long term in the watershed, and has received significant study and monitoring. Despite the elevated bacterial concentrations in tributaries that feed the two estuaries, the estuaries themselves, particularly the Webhannet, show much lower levels during the winter recreational clamming season. The summer geometric mean for enterococci bacteria along Wells and Drakes Island beaches is well below the EPA risk level, indicating that the bacterial contamination from the watersheds appears to be thoroughly flushed by offshore water. Continued monitoring by the Department of Marine Resources ensures that long-term patterns in bacterial contamination will be recorded and reviewed. The continued participation by the town of Wells in the Maine Healthy Beaches Program is also a positive step towards a protecting pulic health and should certainly continue.

References

Agency for Toxic Substances and Disease Registry (ATSDR), Center for Disease Control. 1995. Public health statement for polycyclic aromatic hydrocarbons. Available from http://www.atsdr.cdc.gov/toxprofiles/phs69.html. Accessed July 13, 2006.

Bricker S.D., D., Lipton, A. Mason, M. Dionne, D. Keeley, C. Krahforst, J. Latimer and J. Pennock 2006. Improving methods and indicators for evaluating coastal water eutrophication: a pilot study in the Gulf of Maine. Report to NOAA-CICEET. 66 pp.

Bright, C.S. 1996. Webhannet River sanitary survey: methods and results. Wells National Estuarine Research Reserve, Wells, ME.

Canfield, S.K.E. 2000. Chemical analysis of heavy-metal contamination and its relation to land use in the Webhannet River marsh. Honors thesis, Bates College, Lewiston, ME

Chen, C. Y., M. Dionne, R. A. MacKenzie, A. Bilgili and B. Mayes. 2004. Bioaccumulation of metals in intertidal food webs. Abstract Book, pp. 27. American Society of Limnology and Oceanography Ocean Research Conference, Honolulu, Hawaii.

Dalton, C., F. Dillon, S.D. Bricker, and M. Dionne. 2006. Synthesis of SWMP Data for ASSETS Eutrophication Assessment of the North Atlantic Region NERR Systems. Report to CICEET (Grant number NA-04NOS4190109). 92 pp.

Holden, William F. 1997. fresh water, suspended sediment, and nutrient influx to the Little River and Webhannet River Estuaries, Wells, Maine. Dissertation, Boston University. Boston, ME. 258 pp.

Kelly, J.R. 1996. Dissolved oxygen levels in Maine estuaries and embayments. Maine Department of Environmental Protection and Wells National Estuarine Research Reserve, Wells, ME. 74 pp.

Kelly, J.R. 1997. Final report dissolved oxygen in Maine estuaries and embayments: 1996 results and analyses.Maine Department of Environmental Protection and Wells National Estuarine Research Reserve, Wells, ME. 95 pp.

Maine Department of Environmental Protection. Undated. A decade of toxic monitoring along Maine's coast. Available from http://www.maine.gov/dep/blwq/docmonitoring/toxics/index.htm. Accessed June 30, 2006.

Maine Department of Environmental Protection. 1999. Classification of Maine Waters. Available from www.state.me.us/dep/blwq/docmonitoring/classification/index.htm. Accessed June 30, 2006.

Maine Department of Environmental Protection. 2002. Mercury in Maine: a status report. Prepared for the Joint Standing Committee of the Maine Legislature having Jurisdiction over Natural Resources. Available from http://www.state.me.us/dep/mercury/mercury_in_maine.pdf. Acessed 2006.

Maine Department of Environmental Protection. 2004. 2004 Integrated Water Quality Monitoring and Assessment Report. Document DEPLW0665.

Maine Healthy Beaches Program. 2006. Partnership between Maine State Planning Office, Univ. Maine Cooperative Extension/Maine Sea Grant, Maine Dept. of Human Services/Health Engineering, and Town of Wells, Maine. Available from

http://www.mainehealthybeaches.org/. Accessed July 5, 2006.

Maine Statutes, Title 38, Chapter 3: Protection and Improvement of Waters. Available from http://janus.state.me.us/legis/statutes/38/title38ch3sec0.html . Accessed June 30, 2006.

Mercury Deposition Network. 2006. National Atmospheric Deposition Program. Available from http://nadp.sws.uiuc.edu/mdn/. Accessed July 6, 2006.

NOAA Coastal Services Center. 2005. Wells, Maine, National Estuarine Research Reserve Community Characterization. Report submitted to Wells National ERR.

Ryan P.A., H.R. Hafner and S.G. Brown. 2003. Deposition of air pollutants to Casco Bay. Report prepared for Casco Bay Estuary Project, Univ. of Southern Maine. 117 pp.

Sebold, K.R. 1998. The low green prairies of the sea: economic usage and cultural construction of the Gulf of Maine salt marshes. Dissertation, University of Maine, Orono, ME. 332 pp.

Smith, M. and H. True. 2004. Merriland River, Branch Brook, and the Little River (MBLR.): nonpoint source pollution management plan. Wells National Estuarine Research Reserve, Wells, ME. 55 pp.

Southern Maine Regional Planning Commission. 2000. Profile of General Demographic Characteristics. Available from www.smrpc.org/census/censusprofiles/Wells.pdf, [accessed July 5, 2006]

Tyrrell, M.C. 2005. Gulf of Maine habitat primer. Gulf of Maine Council on the Marine Environment. 54 pp.

Ward L.G. 1993. Precipitation, streamflow and water characteristics (physical and chemical) of the Webhannet River Estuary, Wells, Maine. NOAA Technical Memorandum. Dept. of Earth Sciences, Jackson Estuarine Laboratory, Univ. of New Hampshire.

Ward L.G. 2004. Variations in physical properties and water quality in the Webhannet River estuary (Wells National Estuarine Research Reserve, Maine). Journal of Coastal Research Special Issue 45:39-58.

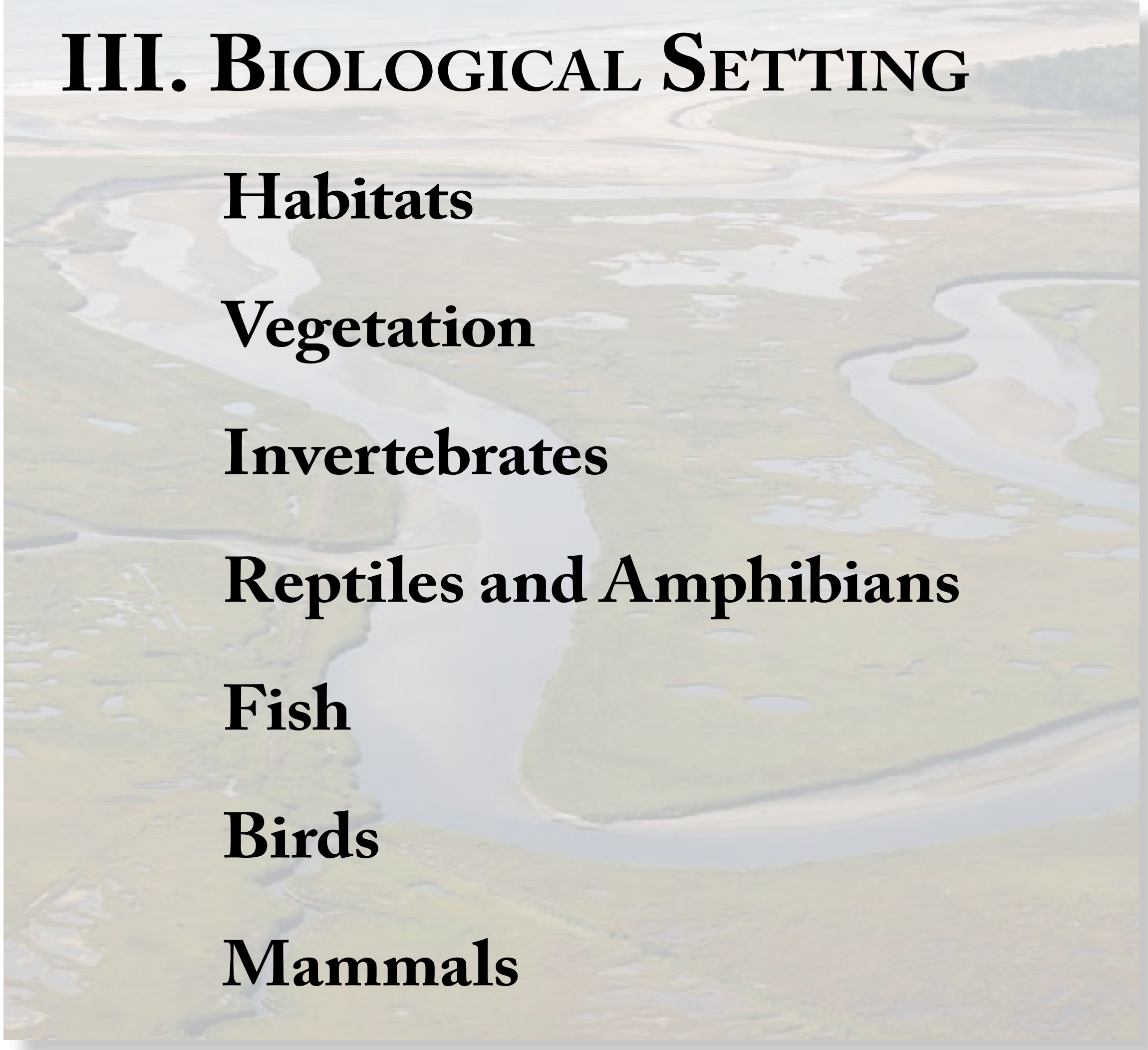
Wells National Estuarine Research Reserve. 2001. Watershed inputs of non-point source pollution to the Webhannet estuary. Submitted to the Gulf of Maine Council on the Marine Environment. 27 pp.

Whiting-Grant K, C Dalton, F Dillon. 2003. Microbial Source Tracking in Two Southern Maine Watersheds: Webhannet Watershed. Report prepared for Cooperative Institute for Coastal and Estuarine Environmental Technology. Maine Sea Grant Report Number MSG-TR-03-01. available from http://www.seagrant.umaine.edu/mst.htm

Whiting-Grant K, C Dalton and F Dillon. 2004. Microbial Source Tracking in Two Southern Maine Watersheds: Merriland River, Branch Brook, Little River (MBLR) Watershed. Report prepared for Cooperative Institute for Coastal and Estuarine Environmental Technology. Maine Sea Grant Report Number MSG-TR-04-01. available from http://www.seagrant.umaine.edu/mst.htm

United States Census Bureau. 2003. State and County Quick Facts, York County, Maine. available from http://quickfacts.census.gov/qfd/states/23/23031.html [accessed June 30, 2006]

United States Food and Drug Administration. 2000. National Shellfish Sanitation Program Model Ordinance available from http://vm.cfsan.fda.gov/~ear/nsspotoc.html [accessed June 30, 2006]



III. Biological Setting

Habitats

Vegetation

Invertebrates

Reptiles and Amphibians

Fish

Birds

Mammals

CHAPTER 7

Habitats

MEGAN TYRRELL

The Wells NERR is unusual within the state of Maine in that its major habitat types are sandy beach, mudflats and marsh. Maine, and the larger Gulf of Maine ecosystem, is noted for its abundance of rocky substrates, particularly the rocky coast. The Reserve does not have any naturally occurring rocky habitats within its boundaries, although there is extensive low intertidal and subtidal cobble habitat and some exposed ledge adjacent to the Reserve's barrier beaches.

DISTRIBUTION OF HABITAT TYPES

The habitats described in this chapter are defined primarily by physical attributes and secondarily by the presence of conspicuous organisms (e.g., marsh vegetation) that create and maintain physical structure utilized by other organisms. Although many factors contribute to the character and quality of habitat that a particular area affords, substrate type (sediment or rock) and sediment grain size are easily discernable factors that are commonly used to define discrete habitat types. The period of tidal inundation also exerts a strong influence over physical conditions and species composition of intertidal and shallow subtidal habitat. Therefore, where relevant, distinctions are made between intertidal and subtidal zones. Biogenic habitats such as salt marshes are distinguished by an abundance of one or more species that substantially modify the physical environment and thus are associated with a distinct biological community. Such communities can interact with physical processes, developing new

View of the Little River mouth. Photo Wells NERR.

Figure 7-1: A pool in a meadow marsh. Drawing by Robert Shetterly.

functions that maintain the habitat type. For example, salt marshes accumulate sediment to match the rate of sea level rise.

Salt Marshes

Salt marshes are grass-dominated, tidally influenced ecosystems that occur in wave-protected embayments (see photo of the flooded Little River marsh, sheltered behind a barrier beach) and along the lower reaches of rivers. All plants in salt marshes have some degree of salt tolerance, termed halophytes. At their most landward extent, salt marshes grade into brackish and fresh tidal marshes, but only salt marshes will be discussed here. There are two basic types of salt marsh, meadows and fringing, which differ in their areal extent and relative abundance of low and high marsh grasses. Fringing marshes form in bands along shorelines where there is protection from wave and wind energy but slope limits the landward extent of the marsh. Salt marsh meadows are wide expanses of marsh dominated by high marsh plants in quiescent areas, such as behind barrier beaches where they are protected from wave and wind energy. Meadow marshes typically have a distinct bank between open water and marsh; and they support a greater diversity of habitat types and landscape scale features, including high marsh and border plant communities, marsh pannes (Fig. 7-1) and pools, and creeks (pictured in section on muddy sediments).

Clouds over the Little River, sheltered behind the barrier beach. Photo Susan Bickford.

The Wells NERR has meadow marshes with tall, narrow stands of smooth cordgrass, *Spartina alterniflora*, at the seaward edge and extensive areas of high marsh dominated by salt marsh hay, *Spartina patens,* landward of smooth cordgrass. The transition zone between smooth cordgrass and salt marsh hay generally denotes the elevation of mean high water. In the high marsh, other common species include black rush, *Juncus gerardii*, spike grass, *Distichlis spicata*, sea lavender, *Limonium nashii*, glasswort, *Salicornia europea*, and the short form of Smooth cordgrass (Tiner 1987). In the salt marsh upland border, diversity increases and common species include marsh elder, *Iva frutescens,* seaside goldenrod, *Solidago sempervirens*, and switch grass, *Panicum virgatum*. Both *Iva* and *Baccharis* occur in salt marshes just to the south of the Reserve, in New Hampshire, but are not present at the Reserve. An invasive genotype of the common reed, *Phragmites australis*, is becoming increasingly common in salt marshes throughout the Northeast. At the Wells NERR, its distribution is limited to the upland border of the meadow marshes, and in impounded areas of marsh. A section devoted to *Phragmites* follows the salt marsh habitat description.

Colonization of mudflats by smooth cordgrass contributes to sediment accumulation and initiates the marsh building process. The major peat-forming plant is salt marsh hay and thus its success is vital for the marsh to accumulate plant material and sediments in pace with sea level rise. salt marsh hay has less tolerance for immersion than smooth cordgrass and therefore both species are necessary for the marsh building and maintenance process; smooth cordgrass colonizes and salt marsh hay builds up the marsh. Old tree stumps that are occasionally unearthed in salt marshes, testify that marshes historically were able to accrete sediment to keep pace with rising sea levels.

Salt marshes are one of the most productive ecosystems in the world and much of their production is exported as detritus to adjacent habitats. The high rates of primary productivity in this habitat type result in significant uptake of atmospheric carbon dioxide, a major greenhouse gas. The root systems of salt marsh plants trap sediment (which often contain pollutants from uplands) and lead to improved water quality. In addition, the salt marsh grasses absorb some of the excess nutrients found in groundwater and runoff, thus reducing the risk of eutrophication in adjacent water bodies. Salt marshes buffer uplands from storm action by absorbing storm surge, thus preventing property damage from flooding and wave energy. Finally, salt marshes reduce erosion by slowing water flow, thus allowing particles to settle out of the water column.

Salt marshes substantially contribute to estuarine and marine food webs. Despite the fact that most of the primary production of a salt marsh is exported, there are a variety of species that consume the vegetation *in situ*. canada geese, *Branta canadensis*, snow geese, *Chen caerulescens*, and a suite of invertebrate species (especially insects, snails, and crustaceans) directly consume salt marsh vegetation. Overgrazing by geese can also turn salt marshes into bare mudflats, threatening the persistence of this habitat type (Bertness *et al*. 2004). Historically, salt marsh grasses were also a food source for grazing livestock and areas of the marsh in both the Little River and Webhannet estuaries have remnants of the fencing that was used to contain cattle that grazed the marsh grasses.

August at the creek edge of a marsh meadow. Note the smooth cordgrass (tall grass at bottom right) and the mud flat visible in the center. Photo by James Dochtermann.

Salt marsh bacteria and infauna (e.g. deposit feeding worms) are responsible for breaking down dead plant material thus producing food particles that sustain suspension feeders such as shellfish. Many species of fish feed, breed, and find refuge in tidal channels, or on the flooded surface of the marsh, and salt marshes are critical resting and feeding grounds for a wide variety of migratory birds. Salt marshes serve as nursery areas for fish, shellfish, crabs, and shrimp because the physical structure of grass prevents larger predatory organisms from reducing the abundance of prey in the marsh. Several fish species such as mummichogs, *Fundulus heteroclitus,* and Atlantic silversides, *Menidia menidia*, spend the majority of their lives in the marsh; fishes such as the sticklebacks use the marsh as spawning habitat; and many fishes inhabit salt marshes as juveniles including winter flounder, *Pseudopleuronectes americanus,* Atlantic menhaden, *Brevoortia tyrannus,* Atlantic herring, *Culpea harengus*, striped bass, *Morone saxatilis,* and pollock, *Pollachius virens*. Birds that nest in marshes at the Wells NERR include: canada geese, and various salt marsh sparrow species, *Ammospiza* sp., some of which are endangered.

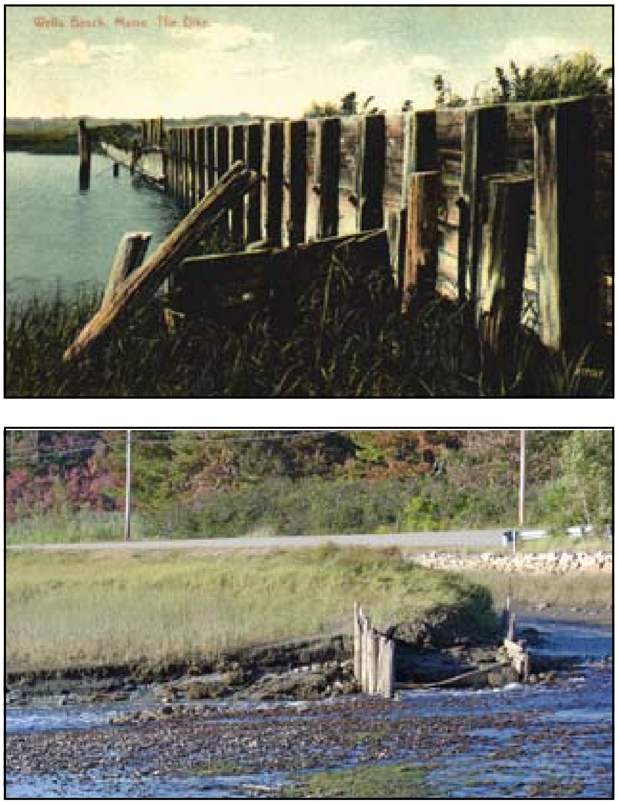
Raptors hunt for small mammals among the grasses and fox also traverse the marsh in search of food.

The most common fish species of the Reserve's marshes include: mummichogs, *Fundulus heteroclitus*, fourspine sticklebacks, *Apeltes quadracus*, ninespine sticklebacks, *Pungitius pungitius*, Atlantic silversides, *Menidia menidia*, and American eel, *Anguilla rostrata*. The most common invertebrates include: grass shrimp, *Palaeomonetes pugio*, sand shrimp, *Crangon septemspinosa*, green crabs, *Carcinus maenas,* clam worms, *Neathanes virens*, soft-shell clams, *Mya arenaria,* common periwinkles, *Littorina littorea* and various species of oligochaete worms.

In addition to the critical ecosystem functions that salt marshes provide, they also provide economic value. Several commercially or recreationally important species such as winter flounder, *Pseudopleuronectes americanus*, striped bass, *Morone saxatilis,* and Atlantic herring, *Clupea harengus*, depend on salt marsh habitats for at least one portion of their life cycle. Other species that use the marsh, such as the Atlantic silverside, sand lance, *Ammodytes americanus*, and American eel, are important as forage for larger piscivorous fishes. Salt marsh hay can be used as livestock feed and high quality garden mulch.

Recreational activities for naturalists abound in salt marshes because of the variety of organisms readily observed in marshes. For example, bird watching is a popular activity in salt marshes and kayakers frequent salt marsh tidal channels. In addition, many educational programs, stewardship programs, and volunteer monitoring are conducted in salt marshes because of the accessibility of this habitat type. Sport fishing is also a valuable activity in salt marsh habitats. A salt marsh view also markedly inflates real estate values.

Embedded stumps provide evidence of marsh accretion and expansion over the upland in response to sea level rise. Photo Michele Dionne.



Dikes were used to protect sections of the Webhannet marsh from flooding, so that cattle could graze more easily. Above: photo from an old postcard of Wells. Below: a dike in the Webhannet today. Photo Wells NERR.

Historically, salt marshes were filled, dredged, and drained for urban and port development. Salt marshes were frequently ditched for salt hay production and later for mosquito control from the 17th century to the 1930's. Unfortunately, digging mosquito ditches to drain upper portions of marsh (believed to be mosquito nursery areas) actually led to increased mosquito populations because predatory killifish were unable to remain in the drained sections of marsh to feed on mosquito adults and larvae. Ditches also altered the level of the water table and shifted vegetation patterns, ultimately altering the quality of salt marsh habitat for wildlife (Roman *et al*. 2000). To increase the availability of palatable plants for cattle grazing, many salt marshes in our region were also historically diked to reduce tidal inundation. The remnants of these dikes are still visible in the Webhannet River marsh near the Drakes Island road (pictured). Construction of seawalls or groins can also lead to erosion of salt marshes because they interrupt natural sediment transport processes.

Other historic threats to salt marshes include dredged material disposed directly on the marsh surface. Burial smothers the vegetation and eventually leads to marsh loss as the buried roots decompose and lose their ability to retain sediments. Highways, roads, and railroads were also built through marshes and currently divide many salt marshes (e.g. the tidal restriction connecting Drake's Island with the mainland); this fragmentation reduces the natural tidal exchange and flushing of the marsh and restricts animal movement. Many of the culverts that were placed under roadways to prevent road flooding were not properly sized, creating tidal restrictions and facilitating the spread of *Phragmites* (pictured). *Phragmites* spreads rapidly under reduced salinity conditions and can outcompete other vegetation such as Salt marsh hay. Monotypic stands of *Phragmites* lower biodiversity and provide poor habitat for native species.

Salt marshes are affected by indirect and cumulative impacts, such as nonpoint source pollution and stormwater from upland development and accelerated sea level rise. Eutrophication often results from development thus shifting plant community composition to favor *Phragmites* at the upland edge of the marsh and allowing smooth cordgrass to shift its distribution upward into the high marsh (Bertness *et al*. 2002). Construction of infrastructure (e.g. seawalls, roads, and driveways, homes, and commercial buildings) immediately upland of salt marshes prevents their natural landward migration. Dock and pier construction over salt marsh kills salt marsh plants through shading and physical disturbance. Improper erosion prevention measures in upland construction projects leads to excessive sedimentation that smothers marsh flora and fauna.

If docks are not designed to minimize shading, they will lead to marsh loss much greater in area than their actual footprint. Photo Michele Dionne.

PHRAGMITES AUSTRALIS

Phragmites australis, or common reed (pictured), is a tall grass (up to 5 m) that occurs along the borders of freshwater aquatic communities (rivers, lakes, etc.) and along salt marshes in areas of reduced salinity. When allowed to expand from the high marsh to the low marsh through clonal integration, *Phragmites* can tolerate areas exposed to full strength seawater (Amsberry *et al*. 2000). It is a perennial species, with standing litter persisting through the winter. The distribution and abundance of this species has increased dramatically along the Atlantic coast within the last 150 years (Saltonstall 2002). A non-native genotype of this species has displaced native strains and spread into areas where *Phragmites* did not historically occur (Saltonstall 2002). The introduced form of *Phragmites* has spread rapidly in degraded areas or areas with naturally low salinity forming extensive monotypic stands.

Phragmites can reproduce and spread in a variety of ways. Its most common method of expansion is through underground rhizomes. It also produces seeds that are small enough to be wind borne. *Phragmites* produces stolons (a shoot that grows horizontally over the ground), which

Phragmites austrails along the pathway to Laudholm Beach. The reed stands even when dry. Photo Hannah Wilhelm.

help it spread over bare surfaces. The general pattern of *Phragmites'* spread is through small isolated patches that coalesce as distinct patches expand (Lathrop *et al*. 2003).

Factors that contribute to the successful establishment of *Phragmites* are generally related to low salinity conditions, such as may result from upland construction or tidal restrictions. Areas that are most susceptible to *Phragmites* invasion include the upper portion of salt marshes, especially those marshes that have been disturbed by fill or other human impacts (Bertness *et al*. 2002). In disturbed environments, *Phragmites* is a superior competitor over some native salt marsh species such as *Juncus gerardii, Lythrum salicaria* and especially smooth cordgrass (Fig. 7-3, Burdick and Konisky 2003).

Various management methods have been successfully used to control the spread of *Phragmites* along the Atlantic coast. One of the most effective and commonly utilized tools is to remove tidal restrictions or to increase the size of culverts to restore thorough tidal flushing to the marsh (Fig. 7-3, Blossey 2003). Selective application of herbicide, prescribed burning and physical removal of plants have also been used to eradicate or slow the spread of *Phragmites*. Biological control using one of *Phragmites* natural enemies, the European Beetle, *Rhizedra lutosa*, does not appear to have strong influence over *Phragmites* stands (Casagrande *et al*. 2003).

Lathrop *et al*. (2003) reviewed the effects of *Phragmites* establishment on the structure and function of mid-Atlantic salt marshes. Increased sediment accumulation rates caused by dense stands of *Phragmites* may change marsh drainage patterns by causing the disappearance

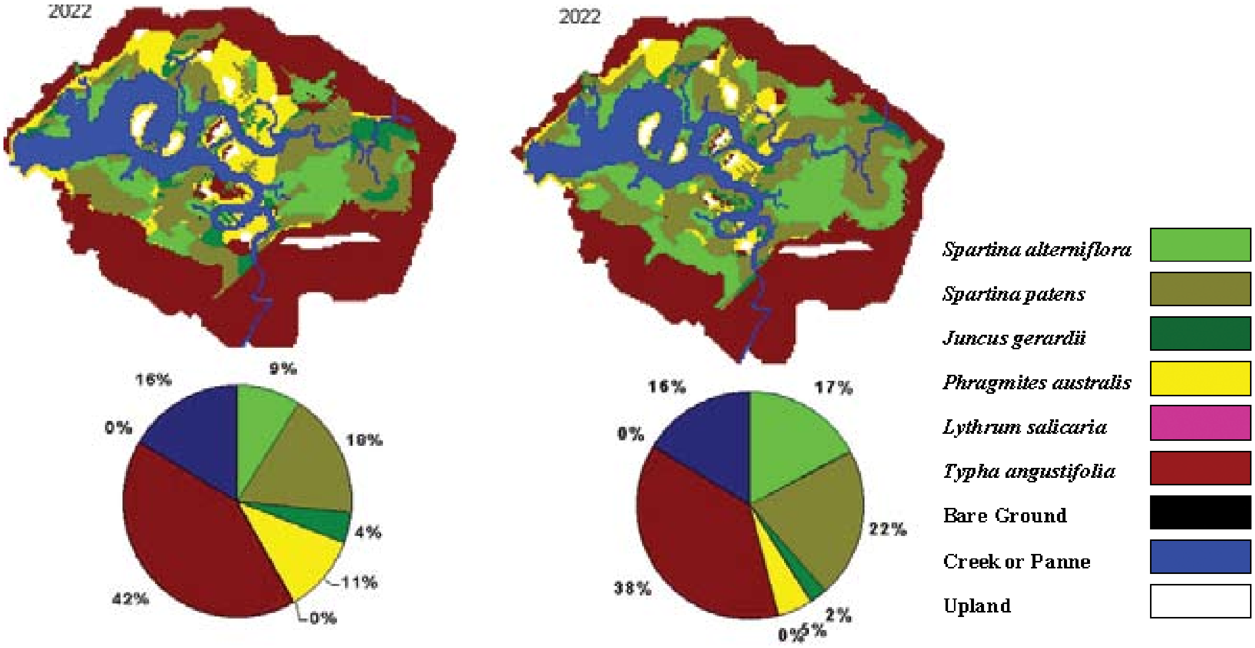


Figure 7-3: Predictions of changes in plant cover over a 20 year period in the Drakes Island marsh (eastern terminus of the Webhannet marsh), based on Konisky and Burdick (2003, 2004). Cover map on left indicates spread of common reed if existing restrictive culvert remains in place under Drakes Island Road. Cover map on right indicates changes if recommended improvement to tidal exchange (I. e. culvert expansion) is implemented.

of some small intertidal channels. Eventually *Phragmites* expansion leads to a decrease in flooding and an increase in the proportion of high intertidal habitat. In addition, the organic matter produced by *Phragmites* fills in the microtopography of the marsh surface, thus reducing the availability of puddles used by mummichogs, *Fundulus heteroclitus,* as spawning and nursery habitat (Osgood *et al*. 2003; Raichel *et al*. 2003). Flow across *Phragmites* dominated marshes is sheet-like because of the filled, continuous surface, while in *Spartina* dominated marshes drainage occurs via rivulets and small creeks (Raichel *et al*. 2003). Because *Phragmites* is taller than typical salt marsh vegetation, once established, it blocks light to other plants and reduces their growth and survival (Burdick and Konisky 2003). *Phragmites* also has some positive attributes through increased primary production, carbon storage and erosion control as compared to native salt marsh vegetation (reviewed by Burdick and Konisky 2003). *Phragmites* dominated systems have very high rates of sediment accumulation (due to high production, lack of export of litter and slow decay rates) and may help to stem the threats of rapid sea level rise that currently threaten many coastal marshes (Rooth *et al*. 2003).

Unlike some other salt marsh plants, *Phragmites* persists as standing litter throughout the winter. Some bird species such as common yellowthroats, *Geothlypis trichas*, marsh wrens, *Cistothorus palustris*, various salt marsh sparrow species, *Ammospiza* sp., are increasingly utilizing *Phragmites* stands as roosting habitat during seasons when other salt marsh vegetation is flat (J. Smith, Massachusetts Bays Program, pers. comm.). Additionally, red-winged blackbirds, *Agelaius phoeniceus,* and long-legged wading birds such as little blue heron, *Egretta caerulea,* snowy egret, *E. thula,* cattle egret, *Bubulcus ibis,* and black-crowned night heron, *Nycticorax nycticorax*, nest in *Phragmites* stands (Parsons 2003).

Several investigations have revealed variable results regarding the trophic value of *Phragmites* versus salt marsh hay and smooth cordgrass-dominated marshes depending on the spatial scale of the study and the trophic levels that were examined. Nevertheless, the suite of organisms that consume *Phragmites* are likely to be different from those that graze on salt marsh hay and smooth cordgrass, thus secondary consumers (such as mummichogs, *Fundulus heteroclitus*) that consume salt marsh grazers are likely to be affected by a switch in dominance from salt marsh hay and smooth cordgrass to *Phragmites* (e.g. Raichel *et al*. 2003). Able *et al*. (2003) found that the spotfin killifish, *Fundulus luciae*, was only found in marshes dominated by salt marsh hay and smooth cordgrass, and they suggested that marsh fish diversity may be reduced as *Phragmites* replaces these species. Similarly, species that have strong affinities for tidal creeks, such as the grass shrimp, *Palemonetes pugio,* may decline in abundance as *Phragmites* expands and fills in small tidal creeks (Osgood *et al*. 2003).

Phragmites australis can grow to extreme heights. It readily colonizes marsh areas with reduced salinity or nutrient enrichment from runoff. Photo Wells NERR

The thicket-like structure of *Phragmites* located along creek banks may block access of non-resident nekton (e.g. fish, swimming crustaceans) to the salt marsh. Other organisms that could have their movements and foraging activities inhibited by the presence of *Phragmites* include wading birds, raptors and mammals.

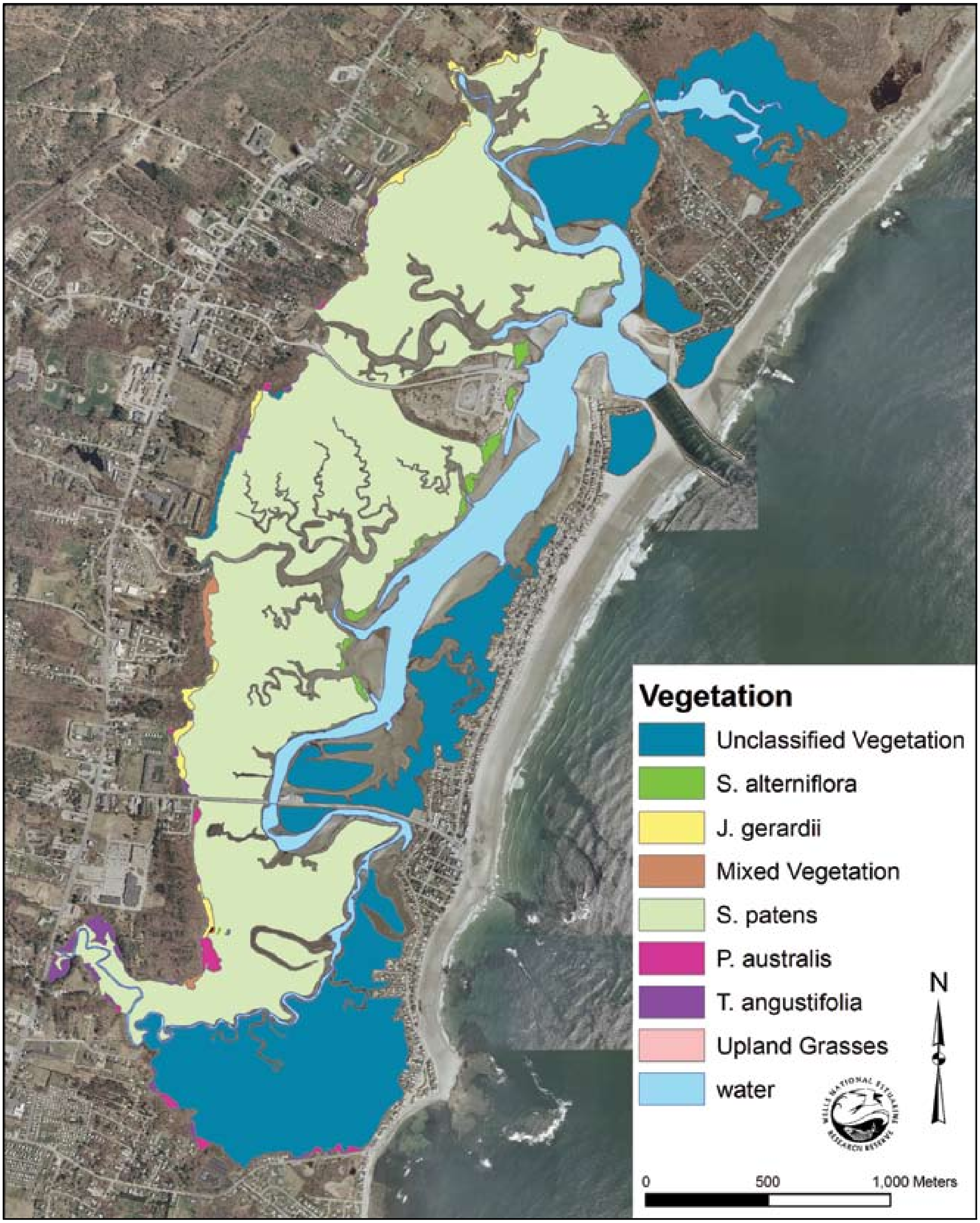


Figure 7-4: Primary plant distribution on the Webhannet marsh. Species having > 50% cover are indicated. There are some areas dominated by *Spartina alterniflora* (tall form) directly adjacent to channel and creek edges that are not indicated on this map. Map Matt McBride.

The height of *Phragmites* obscures salt marsh views for coastal landowners, thus potentially reducing property values. Dry *Phragmites* standing litter also renders it a significant fire risk; brisk coastal winds can rapidly spread a small *Phragmites* brush fire. Concerns regarding the negative impact of *Phragmites* on habitat value and trophic support for fisheries species have spurred *Phragmites* removal efforts in some areas (Grothues and Able 2003). However, the economic impact of *Phragmites* invasion has not been quantified for coastal fisheries species. *Phragmites* dominance is likely to reduce the recreational value of salt marshes because bird watching is hindered by the height of the vegetation. In addition, hydrological changes due to *Phragmites'* enhanced sediment accumulation rate are likely to reduce the recreational value of marshes for kayaking and fishing.

Muddy Sediments

Muddy bottoms are areas of unconsolidated fine-grained sediments that are unvegetated or only periodically sparsely vegetated by green algae (e.g. *Ulva lactuca* and *Enteromorpha intestinalis*) and benthic diatoms. Sediments of muddy bottoms can range in grain size from pure silt to mixtures containing higher proportions of clay and sand. The fine grain size of muddy bottoms harbors higher percentages of organic-mineral aggregates (detritus) than primarily sandy sediments (Whitlatch 1982). Muddy bottoms appear relatively featureless except for burrows and depressions made by animals and small ripples left by wave action. Burrow construction is facilitated by the cohesive nature of muddy sediments. Muddy bottoms are found in depositional, wave-sheltered environments in both the subtidal and intertidal zone (they are commonly referred to as tidal flats in the intertidal zone). Watling (1998) estimates that muddy bottoms in the Gulf of Maine harbor approximately 1,000 species of macroinvertebrates, testifying to the importance of this habitat type in supporting high biological diversity.

Juncus gerardii, photographed along one of the long-term vegetation monitoring transects, is distinguished by its dark seed heads. Photo James Dochtermann.

Intertidal Flats

Mud and sand flats are distributed in wave-protected habitats such as behind barrier beaches or on the down-current side of jetties. Most of the organisms that bury

Marsh meadow with a muddy-bottom creek cutting through. Photo James Docherterman.

Left: A mud flat at low tide. Right: A closer look reveals decaying roots of smooth cordgrass. Photos James Dochtermann.

in soft sediments live within a few centimeters of the surface because mud typically becomes anoxic close to the surface. To adjust to these harsh physical conditions, many organisms build and maintain burrows or tubes, while some have adaptations such as siphons (tubes for filter feeding). Many of the organisms that bury in mud bottoms are suspension feeders; they obtain food particles from the water column and thus act to transfer energy from the water column to the benthos. Deposit feeding, which involves ingestion of sediment and extraction of organic material, is also a common feeding mode in muddy sediments. The tube-dwelling amphipod, *Corophium volutator*, is both a deposit feeder and a filter feeder. It can occasionally be observed moving across the mud flats at the Wells NERR. Its extremely high densities (up to 60,000 m^{-2}) in the Bay of Fundy are a major food source for migrating birds that stop in the mudflats and it likely serves a similar function in southern Maine tidal flats. Some of the bird species that use tidal flats as stopover foraging habitats include: semipalmated sandpiper, *Calidris pusilla*, least sandpiper, *Calidris minutilla*, semipalmated plover, *Charadrius semipalmatus*, red knot, *Calidris canutus*, and short-billed dowitchers, *Limnodromus griseus.*

The productivity of tidal flats is not as high as that of salt marshes (Whitlatch 1982), but their function in the conversion of primary production (plant material) to secondary production (prey) is nonetheless a valuable ecosystem function. When mussels and clams and other filter feeders are abundant in soft sediments, they provide a vital link between water column and benthic habitats by transferring productivity to secondary consumers. The high density of crustacean and molluscan prey in tidal flats supports large numbers of shorebirds during migration. The federally endangered piping plover, *Charadrius melodius,* and many heron and duck species also feed in tidal flats. Terrestrial mammals such as foxes and raccoons also forage in tidal flats (Lehihan and Micheli 2001 and references therein).

Tidal flats provide habitat for a diverse array of benthic organisms; many species of shellfish, worms and crustaceans bury in soft sediments. Burrowing species include molluscs (e.g., soft-shell clam, *Mya arenaria*, quahogs, *Mercenaria mercenaria*, *Macoma balthica,* gem clams *Gemma gemma)*, crustaceans (isopods e.g. *Edotea triloba*, amphipods, e.g. *Corophium volutator*), cumaceans, and worms (e.g. oligochaetes, clamworms [*Neanthes virens],* bloodworms [*Glycera dibranchiata*], and nemerteans [e.g. *Cerebratulus luridas*]). These burrowing infauna contribute to nutrient cycling and their activities keep the top couple of centimeters of sediments from becoming anoxic, benefiting other benthic inhabitants. Fecal pellets produced by some infauna effectively change the sediment grain size and stabilize sediments. Epibenthic species characteristic of mud sediments include: mud snails, *Illynassa obseleta*, common periwinkles, *Littorina littorea,* skates (e.g. little skates, *Leucoraja erinacea)* and flatfish such as winter flounder, *Pseudopleuronectes americanus.* Finally, mudflats host spawning aggregations of

High tide at Laudholm Beach. Waves frequently reach past the ends of the concrete seawall. Photo Erno Bonebakker.

horseshoe crabs, *Limulus polyphemus,* and polychaete worms (e.g. *Neanthes virens*).

Because they are located in depositional (low wave and current energy) environments, muddy sediments are especially vulnerable to pollution. Contaminants that are deposited in flats are likely to remain in the sediments rather than get flushed away. Nutrient loading, especially nitrogen, can lead to algal blooms on mud bottoms. When the algae die, anoxic conditions are created underneath the decomposing material.

Like salt marshes, tidal flats also have historically been filled for development purposes. Both intertidal and subtidal mud bottoms are also frequently subject to dredged material disposal. Alterations in the nearshore sediment transport regime that can result from the construction of jetties or other shoreline stabilization structures threaten tidal flats with excessive erosion. Conversely, excessive, rapid sedimentation associated with dumping or mobile fishing gear can smother the feeding structures of filter-feeding burrowing organisms, such as commercially important bivalve mollusc species. In addition, mobile fishing gear also removes sessile epibenthic species, destroying the structural complexity that these species provide for smaller organisms.

Introduced species pose the biggest biological threats to inhabitants of muddy habitats. The European green crab, *Carcinus maenas*, is blamed for suppressing the abundance of the soft-shell clam, *Mya arenaria*, on tidal flats (e.g. Ropes 1968). High population densities of the green crab have diminished clam abundance in the Reserve, as elsewhere in the Gulf of Maine. The common periwinkle, *Littorina littorea*, has also been blamed for consuming the egg capsules of the mud snail, *Illynassa obseleta* (Brenchley and Carlton 1983).

SANDY SEDIMENTS

Sandy substrates in the Gulf of Maine are mostly derived from quartz. The Wells NERR has sand dunes, beaches, and sandy bottoms in the subtidal zone. Like rocky habitats, the size of the sand grains strongly influences the species composition of the associated community. Small grain sizes pack closely together, which renders them less susceptible to re-suspension by wave action and reduced

Sand dunes by the mouth of the Little River. The roots of American beachgrass, Ammophila breviligulata, stabilize sand dunes and the aboveground structure traps sand and prevents erosion. Photo Hannah Wilhelm.

permeability to water. In contrast, coarse-grained sand allows water to percolate downward between grains rather than across the surface. Infaunal organisms are usually restricted to the upper few centimeters of sand where there is sufficient oxygen penetration. Organisms that inhabit sandy environments are generally less susceptible to disturbance than those found in muddy habitats because sandy substrates can be subject to frequent wave generated disturbance. Sand movement strongly influences the abundance and species composition of the benthic community. Highly dynamic areas are populated by species that are adapted to move to avoid being buried or to recover quickly from burial. Stable sandy bottoms (such as those that are too deep to be disturbed by storm swell) generally have higher species diversity than highly dynamic sandy habitats.

Sand Dunes

Sand dunes (see photo) are formed when American beachgrass, *Ammophila breviligulata*, or other objects trap sand blown up from the beach. Large mounds of sandy glacial outwash deposited by glaciers are also referred to as sand dunes although they are not formed by wind. In spite of the fact that dunes are often very dry, salty and subject to continual scouring by winds and waves, many plants and animals utilize this habitat. Besides American beachgrass, other plants that were found in a survey of dune vegetation at the Wells NERR include: beach heather, *Hudsonia tomentosa,* beach pea, *Lathyrus japonicus,* goldenrod, *Solidago rugosa,* Dusty miller, *Artemisia stelleriana,* bayberry, *Myrica pennsylvanica,* and seaside rose, *Rosa rugosa* (Nelson and Fink 1980). Vegetation stabilizes dunes and allows them to maintain their shape despite strong winds and storm surge. Animals that utilize sand dune habitats are mostly terrestrial, including deer, rodents and insects. Common terns, *Sterna hirundo* (Fig. 7-5) and piping plovers, *Charadrius melodius,* are some of the many bird species that nest in dunes. Because humans trample vegetation and disturb nesting seabirds, extensive sand dune re-vegetation efforts and fencing have been undertaken on sandy shores near Wells NERR.

Sandy Beaches

Sand beaches are highly dynamic; their shape, size and location often shift due to wind, waves and storm surge. The shape and grain size of sand beaches change in a predictable manner from summer to winter. A flat, wide intertidal zone composed of fine-grained sand characterizes summer beaches. Winter beaches have a sharper profile, and coarser sand that are created by storm surges that transport fine sand to the subtidal zone. At the Reserve, the upper zone of the sandy beach is relatively depauperate of conspicuous animal life except for nesting shorebirds, because other upper intertidal inhabitants, such as the ghost crab, *Ocypode quadrata*, that are common south of the Gulf of Maine, are lacking. Shells that are likely to be encountered in a quick survey of the

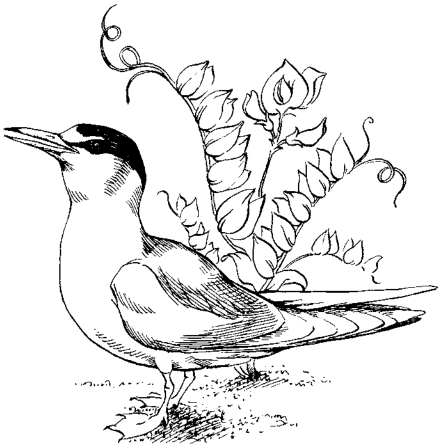


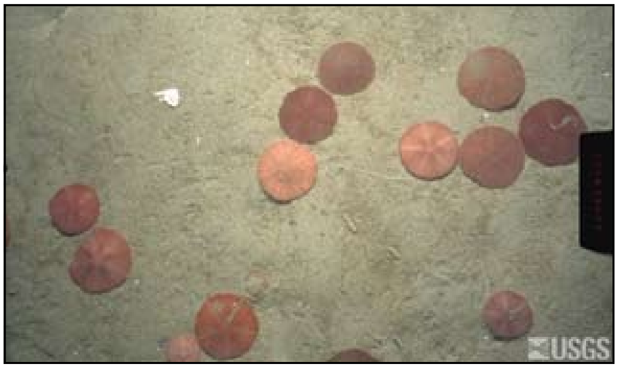
Figure 7-5: Dunes provide habitat for terns and other rare birds. Drawing by Robert Shetterly.

wrack community at the Wells NERR beach includes: jingle shells, *Anomia simplex*, blue mussels, *Mytilus edulis*, surf clam, *Spisula solidissima,* and carapaces from green and Cancer crabs. Many small crustaceans including isopods and amphipods from the family Talitridae (beach hoppers) graze on decaying plant and animal material in the wrack line. fish crows, *Corvus ossifragus*, and various species of gulls, *Larus* sp., sometimes scavenge in the wrack line.

Like sand dunes, sand beaches are relatively harsh environments for marine organisms and the highest densities occur in the surf zone because organic nutrients tend to accumulate there. Inhabitants of the surf zone and shallow subtidal zone include burrowers, such as razor clams*, Siliqua costata*, and jacknife clams, *Ensis directus*, and the digging amphipod, *Haustorius canadensis.* Other characteristic inhabitants of the surf zone that are easily observed, such as mole crabs, *Emerita talpoida*, and the brightly colored coquina clams, *Donax variabilis*, do not occur in the Gulf of Maine because they have southern distributions.

Subtidal Sandy Bottoms

In the subtidal zone, deep sandy bottoms are often flat and relatively featureless because they are unaffected by storm surge. In shallower water, sandy bottoms often have ripples and other bedforms that were shaped by strong currents or storms. Relatively few organisms are exposed on a flat sandy seafloor, they generally bury beneath the sand to avoid predators and currents. Some burying species include predatory moon snails, *Lunatia* sp., sand dollars, *Echinarachnius parma,* lug worms, *Arenicola marina,* and American sand lance, *Ammodytes americanus.* Another adaptation common among sandy-bottom inhabitants is camouflage; flounder, gobies, skates and shrimp are cryptic and are especially difficult to detect visually. Fish that are commonly associated with sandy bottoms include Atlantic halibut, *Hippoglossus hippoglossus*, and various species of flounder. Silver hake, *Merluccius bilinearis*, are commonly associated with sand waves, which provide protection from currents and allow them to ambush prey (Auster *et al.* 2003*).*



Sand dollars are one of the few conspicuous creatures on the sandy sea floor (Gutierrez et al. 2001, US Geological Survey).

Wrack on Laudholm Beach, Summer. Photo Michele Dionne.

Sand beaches are the coastal habitat type most intensively used by humans and perhaps it is not a coincidence that many endangered marine species also use sand beaches and dunes as their habitat. The endangered birds, roseate tern, *Sterna dougallii*, piping plover, *Charadrius melodius* and least tern, *Sterna antillarum*, nest in sand dunes or on the upper sections of sandy beaches. Sand beaches and dunes are subject to intense human use for recreation. Real estate adjoining sandy habitats is highly valued, particularly if the beach is wide. Dunes protect inland areas from storm surge and wind but their natural functions are frequently disrupted by human activities.

Sandy habitats are most commonly utilized as foraging habitats by high trophic levels (animals that eat other animals), and are particularly critical for many shorebirds. The most common feeding modes of lower trophic levels in sandy habitats are filter and deposit feeding. Many species utilize ridges or other bedforms in subtidal sandy bottoms as protection from predation or as cover for ambush. Moon snails consume their bivalve prey while buried beneath the sand surface. Despite the value of sandy habitats to the aforementioned organisms, these habitat types have comparatively low productivity and diversity. In contrast to other habitat types, relatively few commercially exploited species are strictly associated with sandy habitats. Some commercially exploited species that are commonly found on sandy bottoms include surf clams, *Spisula solidissima,* softshell clams, *Mya arenaria,* winter flounder, *Pseudopleuronectes americanus,* smooth flounder, *Pleuronectes putnami,* and Atlantic halibut, *Hippoglossus hippoglossus.*

Two obvious threats to sandy habitats at the Reserve are residential construction and shorefront infrastructure such as jetties and seawalls. Commercial and residential development in the primary dune zone impedes their natural migratory processes and results in buildings that are highly susceptible to flooding and storm damage. In addition, impervious surfaces such as roads and driveways adjacent to sandy beaches can lead to increased erosion resulting from stormwater runoff. In an examination of the effects of human disturbance along sandy coasts, Lercari and Defeo (2003) found reduced species diversity and biomass in addition to reduced beach width and slope in areas affected by freshwater inflows and sewage effluent discharges. Trampling of dune vegetation by humans and domestic animals also leads to dune demise.

Erosion can threaten sand beaches when jetties, groins and seawalls disrupt longshore sediment transport patterns. Domestic animals frequently disturb shorebirds while they are foraging and threaten chicks and eggs when parents are chased off the nest. Finally, intensive beachcombing or mechanized cleaning of beaches result in removal of seaweed, shells and other natural materials that beach inhabitants utilize for food and shelter.

Below the intertidal zone, sandy bottoms are generally less threatened by human activities, with the biggest threat stemming from sand mining for beach re-nourishment. There are less epibenthic species (such as sponges and hydroids) that provide microhabitats for other species on sandy bottoms; so sandy bottoms are thought to be more resilient to trawling-related disturbances than other substrate types. Reduction in abundance of sand dollars and other sandy-bottom residents likely resulted from harbor dredging for beach renourishment near the Webhannet estuary in Sept-Dec 2000.

A footpath through the marsh. Spartina alterniflora is easily trampled and broken. Photo Susan Bickford

CURRENT RESEARCH

The Reserve's salt marshes are intensively utilized by researchers for hypothesis-based research, yet there is little information about how the relative abundance of these different habitat types may be changing over time. In 2005, fieldwork began on a Wells NERR vegetation monitoring project with the goal of mapping the 3 major marsh plant communities (*Phragmites/Juncus/Typha,* Salt marsh hay and *Smooth cordgrass*) in the Little and Webhannet Rivers. The areal extent of these 3 community types will be compared with future mapping to determine if there are shifts in the proportion of marsh dominated by these three plant communities and if the total extent of vegetated marsh is increasing or declining over time. Maine Sea Grant's beach profiling program documents the horizontal and vertical extent of the beach and dune system that protects the Reserve's estuaries, with data collected every month for the past eight years.

RESEARCH NEEDS

Periodic monitoring to assess the rate of sediment accumulation will allow researchers to determine if the Reserve's marshes are keeping pace with local sea level rise. In addition, the extent to which grazing by Canada geese affects marsh productivity should be assessed in the Little and Webhannet Rivers. Algal ecads, especially *Ascophyllum nodosum* ecad *scorpiodes,* form thick mats in the smooth cordgrass zone of both the Little and Webhannet Rivers. Their role in contributing to local marsh production and sediment accumulation is likely very important. In addition, the structural complexity of these algal mats provides protection from sun and desiccation stress, which may lead to enhanced species diversity and abundance of epifauna. The Wells NERR should support research aimed at improving our understanding of the role of algal ecads in marsh systems as well as documenting the extent to which algal ecads in Reserve marshes are derived from local rocky shore habitats. Finally, changes in the abundance of *Phragmites* should also be consistently documented (about every 3-5 years) to allow managers to determine whether *Phragmites* eradication or control measures should be implemented.

MANAGEMENT RECOMMENDATION

As previously mentioned, tidal restrictions are detrimental to the integrity of salt marsh habitats. The widening of the Drakess Island Road culvert into a self-regulating tide (SRT) gate is an important first step in restoring that habitat to a less impacted state. The optimal management regime for the SRT would allow smooth cordgrass and salt marsh hay to re-colonize the upstream area. Heavy foot traffic is partially to blame for marsh bank erosion in the Little River. Restrictions on the number and frequency of humans that are allowed to visit the marsh will alleviate this problem. In addition, paths through the marsh grasses should be re-located each year to allow the plants to naturally recolonize bare areas caused by trampling.

REFERENCES

Able, K.A., S.M. Hagan and S.A. Brown. 2003. Mechanisms of marsh habitat alteration due to Phragmites: response of young-of-the-year Mummichog (*Fundulus heteroclitus*) to treatment for Phragmites removal. Estuaries 26(2B):484-494.

Amesbury, L., M.A. Baker, P.J. Ewanchuk and M.D. Bertness. 2000. Clonal integration and the expansion of Phragmites australis. Ecological Applications 10(4): 1110-1118.

Auster, P.J., J. Lindholm, S. Schaub, G. Funnell, L.S. Kaufman and P.C. Valentine. 2003. Use of sand wave habitats by silver hake. Journal of Fish Biology 62(1): 143-152.

Bertness, M.D., B.R. Silliman and R. Jeffries. 2004. Salt marshes under siege. American Scientist 92:54-61.

Bertness, M.D., P.J. Ewanchuk and B.R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. Proceedings of the National Academy of Science. 99(3): 1395-1398.

Blossey, B. 2003. A framework for evaluating potential ecological effects of implementing biological control of Phragmites australis. Estuaries 26(2B): 607-617.

Brenchley, G.A. and J.T. Carlton. 1983. Competitive displacement of native mud snails by introduced periwinkles in the New England intertidal zone. Biological Bulletin 165: 543-558.

Burdick, D.M. and R.A. Konisky. 2003. Determinants of expansion for Phragmites australis, Common Reed, in natural and impacted coastal marshes. Estuaries 26(2B): 407-416.

Konisky, R.A. and D. Burdick. 2004. Effects of stressors on invasive and halophytic plants of New England salt marshes: a framework for predicting response to tidal restoration. Wetlands 24(2): 434-447.

Casagrande, R.A., G. Balme and B. Blossey. 2003. Rhizedra lutosa, a natural enemy of Phragmites australis in North America. Estuaries 26(2B): 602-606.

Grothues, T.M. and K.W. Able. 2004. Response of juvenile fish assemblages in tidal salt marsh creeks treated for Phragmites removal. Estuaries 26(2B): 563-573.

Konisky, R.A. 2003. Spatial modeling and visualization of habitat response to hydrologic restoration in New England salt marshes. Dissertation, University of New Hampshire, Durham, NH. 305 pp.

Konisky, R.A. and D. Burdick. 2004. Effects of stressors on invasive and halophytic plants of New England salt marshes: a framework for predicting response to tidal restoration. Wetlands 24(2): 434-447.

Lathrop, R.G., L. Windham and P. Montesano. 2003. Does Phragmites expansion alter the structure and function of marsh landscapes? Patterns and processes revisited. Estuaries 26(2B):423-435.

Lenihan, H.S. and F. Micheli. 2001. Soft-sediment communities. Pages 253-288 *In* Marine Community Ecology *Edited by* M.D. Bertness, S.D. Gaines and M.E. Hay. Sinauer, Sunderland, MA. 550 pp.

Lercari, D. and O. Defeo. 2003. Variation of a sand beach macrobenthic community along a human-induced gradient. Estuarine, Coastal and Shelf Science 58(1): 17-24.

Nelson, B.W., and L.K. Fink. 1980. Geological and botanical features of sand beach systems in Maine. Planning Report No. 54. Maine Critical Areas Program Maine State Planning Office, Augusta, ME 169 pp.

Osgood, D.T., D.J. Yozzo, R.M. Chambers, D. Jacobson, T. Hoffman and J. Wnek. 2003. Tidal hydrology and habitat utilization by resident nekton in Phragmites and non-Phragmites marshes. Estuaries 26(2B): 522-533.

Parsons, K.C. 2003. Reproductive success of wading birds using Phragmites marsh and upland nesting habitats. Estuaries 26(2B): 596-601.

Raichel, D.L., K.W. Able and J.M. Hartman. 2003. The influence of Phragmites (Common Reed) on the distribution, abundance and potential prey of a resident marsh fish on the Hackensack Meadowlands, New Jersey. Estuaries 26(2B): 511-521.

Roman, C.T., N. Jaworski, F.T. Short, S. Findlay and R.S. Warren. 2000. Estuaries of the northeastern United States: Habitat and land use signatures. Estuaries 23(6): 743-764.

Ropes, J.W. 1968. The feeding habits of the green crab, Carcinus maenas (L.). Fishery Bulletin 76(2):183-203.

Rooth, J.E., J.C. Stevenson and J.C. Cornwell. 2003. Increased sediment accretion rates following invasion by Phragmites australis: the role of litter. Estuaries 26(2B): 475-483.

Saltonstall, K., 2002. Cryptic Invasion by a Non-Native Genotype of the Common Reed, Phragmites australis, into North America, Proceedings of the National Academy of Sciences of the United States of America 99(4): 2445-2449

Smith, J., Personal Communication. Director, Massachusetts Bay Program. 251 Causeway Street, Boston, Massachusetts 02114.

Tiner, R.W. 1987. Coastal Wetland Plants of the Northeastern United States. The University of Massachusetts Press, Amherst, MA.

Tyrrell, M.C. 2005. Gulf of Maine Habitat Primer. Gulf of Maine Council on the Marine Environment, www.gulfofmaine.org. 54 pp.

Watling. L. 1998. Benthic fauna of soft substrates in the Gulf of Maine. In: E.M. Dorsey and J. Pederson (eds.). Effects of fishing gear on the seafloor of New England. Conservation Law Foundation, Boston, MA. 160 pp.

Whitlatch, R.B. 1982. The Ecology of New England Tidal Flats: A Community Profile. U.S. Fish and Wildlife Service, Biological Services Program, Washington, DC. FWS/OBS-81/01. 125 pp.

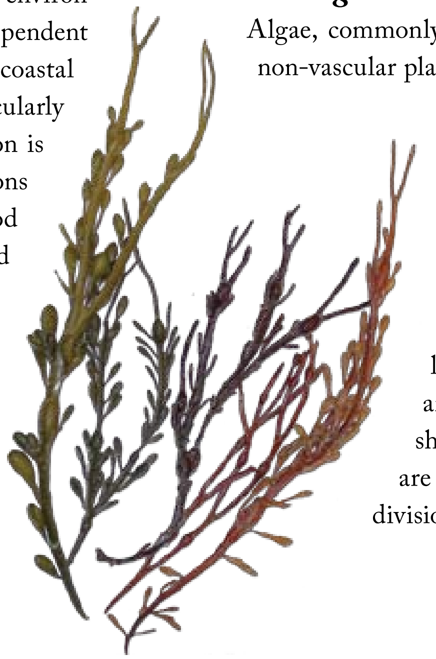
CHAPTER 8

Vegetation

CAITLIN MULLAN CRAIN

Plants are primary producers that use photosynthesis to convert light energy into carbon. Plants thus form the base of all food webs and provide essential nutrition to animals. In coastal "biogenic" habitats, the vegetation also engineers the environment, and actually creates the habitat on which other organisms depend. This is particularly apparent in coastal marshes where the plants themselves, by trapping sediments and binding the sediment with their roots, create the peat base and above-ground structure that defines the salt marsh. The plants thus function as foundation species, dominant organisms that modify the physical environment and create habitat for numerous dependent organisms. Other vegetation types in coastal systems function in similar ways, particularly seagrass beds or dune plants. Vegetation is therefore important for numerous reasons including transforming energy to food sources, increasing biodiversity, and creating habitat.

Major vegetation types in the coastal areas of Wells NERR include macroalgae, submerged aquatic vegetation, and beach dune communities, and marshes (which vary in salinity from salt to brackish to tidal freshwater). In this chapter, we will describe what these vegetative communities look like, special plant adaptations for living in coastal habitats, and important services these vegetative communities perform. We will then review important research conducted in or affiliated with Wells NERR on the various vegetative community types, giving a unique view of what is known about coastal vegetative communities of southern Maine.



COASTAL VEGETATION

Macroalgae

Algae, commonly known as seaweeds, are a group of non-vascular plants that depend on water for nutrient acquisition, physical support, and reproduction. Algae are therefore restricted to living in environments that are at least occasionally inundated by water. Because algae photosynthesize using light reflected through the water, most algae cannot live in dark ocean depths and thus are most common in intertidal and shallow subtidal environments. Algae are generally broken into three major divisions based on their photosynthetic pigments—red, green, and brown—which are used for identification and characterization.

Species diversity of algae is high on southern Maine coastlines, with 148 species of seaweeds recorded in coastal and estuarine environments (Mathieson *et al.* 2001). While many species can be found in this region, coastal habitats defined by algal occupants are less common. Macroalgal communities are dominant on hard substrate, particularly rocky shores. In southern Maine, the shoreline is predominantly soft sediments and macroalgae persists here on occasional hard substrates or in un-anchored forms. Hard substrates on this stretch of coast are typically man-made structures such as docks or jetties, or occasional boulders. These substrates are often colonized by large brown algae, knotted wrack, *Ascophyllum nodosum*, rockweed, *Fucus vesiculosus* or *Fucus spiralis*. These same habitats can be opportunistically occupied, particularly after disturbances or when herbivory by snails is low, by fast growing green algae *Enteromorpha intestinalis* and *Ulva lactuca*. The macroalgal communities have been well studied in their more extensive ranges on rocky shorelines, but their role here is likely very similar. Mats of large brown algae have been shown to alter local environmental conditions by providing a cool, moist habitat favored by many invertebrate species that are otherwise limited from these locations by dessication stress (Bertness *et al.* 1999). Intertidal algae provide a food source for numerous invertebrates and an anchoring site for other epiphytic algae (see kelp fronds pictured). Knotted wrack and rockweed are critical rocky shore organisms, responsible for much of the intertidal productivity and habitat provisioning of these shores. These macroalgae are harvested for packing material in the shellfish industry which can locally threaten macroalgal populations, particularly since reproductive output is relatively low and localized.

"Ecads," a type of algae that become entangled among salt marsh plants and then continue to grow, are the topic of a 2006 research project at Wells NERR. Note the PVC tubing marking a research plot, and the grey-blue algae at the base of the green Spartina alterniflora. Photo Megan Tyrrell.

These dominant brown algae can also be found growing without holdfasts in the low salt marsh community (Mathieson and Dawes 2001, pictured). Here the algae are effectively anchored by growing entangled in and around the roots and shoots of the salt marsh plants. Research has shown that both plants and algae benefit from this association as the plants are more productive, likely due to algal nutrient delivery, and the algae gain anchor sites and are less subject to desiccation (Gerard 1999).

Non-anchored macroalgae can also be found free-floating in the water column as drift algae. Most drift algae originate as attached plants that are disturbed, often resulting in altered morphology and loss of sexual reproduction. A high diversity of algal species can be found as drift algae. High nutrients in the water column, often due to human sources, can cause "blooms" of drift algae which can be quiet harmful to the marine environment, by causing low oxygen conditions, fouling beaches, impacting fisheries and altering marine communities.

Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation (SAV), commonly known as seagrass, are rooted flowering plants (angiosperms) that are specially adapted for surviving life underwater. Subtidal seagrass beds are very productive, supplying food and carbon to adjacent marine communities, and provide habitat and predator refuge to numerous associated invertebrate and fish species. Seagrass beds trap and bind sediments, preventing coastal erosion and driving geomorphology of the shoreline. Beds of eelgrass, *Zostera maritima*, were common historically in shallow coastal areas of New England, but their areal coverage has declined due to nutrient pollution, physical disturbance and disease. These communities are very important for marine health and substantial efforts have been

Kelp fronds anchored by a holdfast to a cobble. Photo Susan Bickford.

directed towards seagrass restoration projects in New England. While seagrass beds are not currently found within Wells NERR, there is some indication that the subtidal mudflats were once colonized by eelgrass (Short *et al*. 1992).

SAV can also be found in permanent ponds within salt marshes. Widgeongrass, *Ruppia martima*, is common and abundant and can tolerate the variable and at times harsh conditions of these marsh pools. Widgeongrass is a favorite and important food source for ducks and waterfowl that pause along migratory routes to fuel up in salt marsh ponds.

Dune Vegetation

Coastal dunes form above the highwater line of sandy beaches and define the terrestrial edge of these habitats. Dunes are dynamic communities that are colonized and stabilized by plants, and through succession can be transformed to more terrestrial environments or can be eroded and return to the sea. Dunes result from onshore winds that blow sand particles up the shoreline until they are deposited and stabilized, usually by wrack, at the high tide line. These "embryo" dunes are unstable and transient unless colonized by plants. Dune plants are specially adapted to these variable conditions, and primary colonizers are tolerant of dry conditions, high salinities and shifting sediments. Many of these plants have similar adaptations for dealing with high salinities and water stress as will be described in the salt marsh plants below, such as succulence, sunken stomates and curled or hairy leaves. These plants are additionally adapted to grow quickly after burial by sand.

As the dune ages, plant roots increase stability and increase organic matter, making nutrients more available. Dunes thus exhibit stages of succession that are mirrored by zonation of plants that vary in their ability to tolerate the varying physical conditions. Typical dune succession is characterized with increasing age by the foredune community, dunegrass community (pictured), dry dune slack community, shrub community and dune forest community (Nelson and Fink 1980). Each community has characteristic plants adapted to the physical conditions and facilitated by plants and their feedbacks in earlier successional stages.

The dominant plant species on foredunes of southern Maine is beach grass, *Ammophila breviluguilata.* Other plants often found in the dunes include dusty miller, *Artemesia stelleriana*, and beach pea, *Lathyrus japonicus.* Dune vegetation is responsible for stabilizing and creating the developing dune community which is an important habitat for other wildlife. Of particular importance

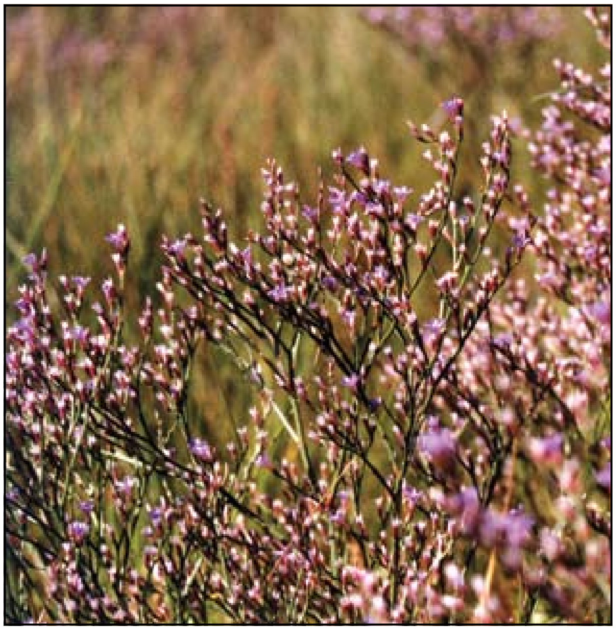
American beachgrass at the edge of a dune at Laudholm Beach. Photo Hannah Wilhelm.

in southern Maine is provision of habitat to endangered seabirds, least terns and piping plovers.

Dune communities are present on the Laudholm Beach where the natural dune remains. However, much of the dune habitat in southern Maine has been removed due to coastal development. Loss of dunes makes shorelines less stable and removes the wave buffering capacity, making coastal habitats much more vulnerable to waves and erosion.

SALT MARSH VEGETATION

Salt marshes develop in protected intertidal environments, and in southern Maine this is generally behind barrier beaches that dissipate wave energy. Vegetation in salt marshes has fairly low diversity, as few plants are adapted to tolerate the challenging physical conditions of these habitats. Inundation with salt water is stressful



Sea lavendar, Limonium nashii, grows in high marsh forb zones. Photo Wells NERR.

Glasswort (Salicornia europaea), the reddish plant in this marsh landscape, is the most salt-tolerant plant on the marsh. It is the first colonizer of disturbed bare substrates that have high soil salinities due to evaporation in the absence of shading by plants. Photo Andrea Leonard.

for plants that have evolved in terrestrial environments. The plants that do inhabit salt marshes are halophytes (salt-tolerant plants, one of the more showy being the salt marsh aster, pictured) that can additionally tolerate waterlogging stress due to tidal flooding. Plant adaptations to salt stress include concentrating solutes in their tissues to counteract salt gradients that otherwise pull water out of the plant. Many plants have salt glands that concentrate and excrete salts onto leaf or stem surfaces and some are succulents that concentrate water in storage cells. Plant adaptations to waterlogging include shallow rooting, or even mounding (see Fogel *et al*. 2004, Crain and Bertness 2005) that enable plants to avoid anoxic sediments, and aerenchyma, hollow stems that allow air to pass from above ground into the waterlogged soils around the roots.

Figure 8-1: Common glasswort, *Salicornia europaea*, is a succulent that sequesters salt in its tissues, turns a distinctive red color in the fall, and often colonizes disturbed areas of the marsh. Drawing by Kristen Whiting-Grant.

Dominant Plant Zones

Dominant plants of New England salt marshes vary across intertidal elevations with smooth cordgrass, salt marsh hay, and black rush occupying the low, mid, and high marsh elevations respectively. These plants are most often found in monotypic (single species) stands that vary predictably with elevation. This typical zonation of plants is driven by plant tradeoffs in tolerance to physical stress versus competitive ability. For instance, the low marsh dominant, smooth cordgrass, can tolerate greater salt and waterlogging stress than the other marsh dominants, but is a poor competitor for resources in the less stressful mid and high marsh elevations. The same tradeoffs hold across the marsh platform, leading to a general rule that a species low marsh distribution is set

Aster tenufolius, the perrenial salt marsh aster, can be found near the wooded upland edge on the Webhannet marsh. Photo Ward Feurt.

by physiological stress, while upper marsh distributions are set by competition with other plants (Bertness and Ellison 1987, Bertness 1991).

In northern New England marshes, a forb panne community, not found farther south, occupies substantial area in mid-tidal elevations. This community is characterized by relatively large amounts of bare space and a high diversity of salt marsh forbs (non-grass, broad-leaved plants). Characteristic plants include seaside lavender (*Limonium nashii*), common arrowgrass (*Triglochin maritima*), seaside plantain (*Plantago maritima*), smooth cordgrass (*Spartina alterniflora*). Research at Wells NERR has discovered that high soil waterlogging makes these habitats particularly stressful and excludes the dominant marsh grasses from occupying these areas, thus providing a competitive refuge for stress tolerant forbs (Ewanchuk and Bertness 2004b). When soils are artificially drained, the forbs lose their competitive refuge and dominant marsh grasses invade and out-compete the forbs (Ewanchuk and Bertness 2004a). These findings led researchers to suggest that the lack of forb pannes in southern New England marshes may be due to the extensive ditching for mosquito control that effectively drained these marshes. This hypothesis is under further investigation. Forb pannes may also be transient features of the marsh that occur after disturbances, particularly from ice. Icing is common in southern Maine, and ice scours leave waterlogged and stressful environments occupied opportunistically by forb panne species (such as glasswort, pictured) that can slowly facilitate succession by dominant marsh grasses (Ewanchuk and Bertness 2003). One plant important in extremely waterlogged pannes, *Triglochin maritima*, can form raised root mounds, or hummocks, on which other plants live. This plant thus serves as an ecosystem engineer that alters the physical environment, thus providing habitat and enabling a plant community to persist that would otherwise be unable to live in these stressful environments (Fogel *et al.* 2004).

While salt marsh plant zonation has been well described (Fig. 8-2, Fig. 8-3), how soil nutrient patterns vary within a marsh have been less often examined. Theodose and colleagues examined soil and nutrient dynamics in three dominant zones (salt marsh hay, black rush, and mixed forbs) in salt marshes of the Wells NERR. They found that differences exist in nutrient availability across marsh zones, specifically phosphorus, salinity and soil moisture were highest in the forb zone, ammonium-nitrogen was highest in the *Juncus* zone, and plant nitrogen was greatest in the forb and patens zones (Theodose and Roths 1999). Nitrogen mineralization rates were highest in the forb zone due to differences in both substrate quality (soil organics and nutrients) and microclimate (temperature and moisture) (Theodose and Martin 2003). It is yet unknown whether these patterns in soil parameters and nutrient dynamics drive or result from vegetation zonation.

Fringing Marshes

Salt marshes not only develop in extensive meadows behind barrier beaches, but may also form fringing marshes that occupy a narrow band along an estuarine

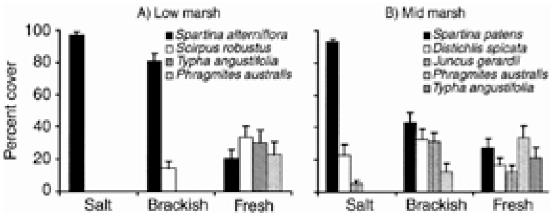


Figure 8-2: The dominant plant species varies depending on elevation. Bars show standard error (n=40) (Crain *et al.*2004). Reprinted with permission from the Ecological Society of America.

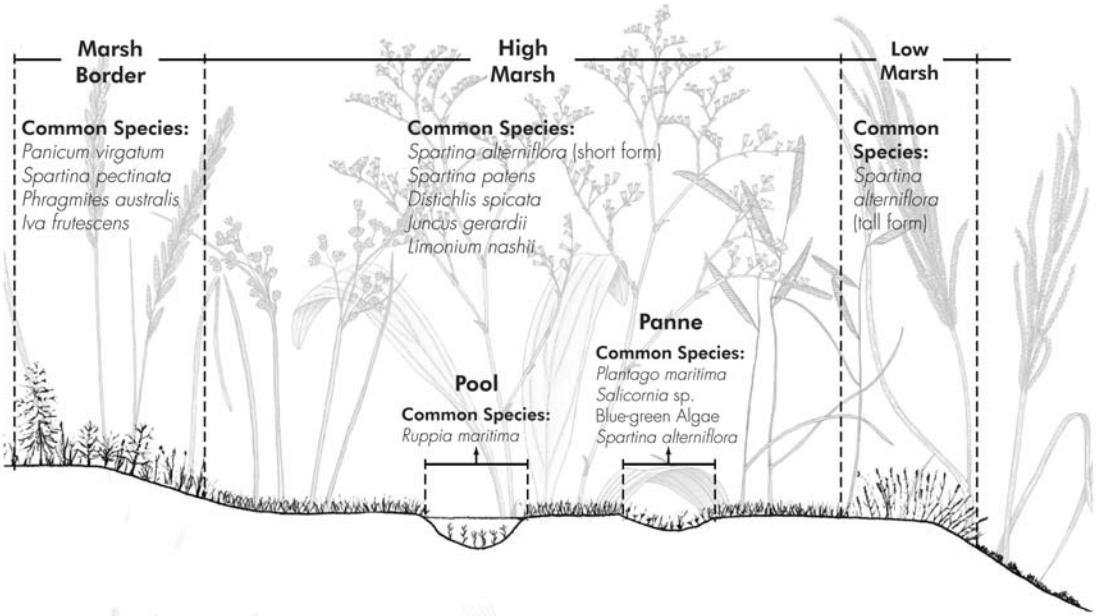


Figure 8-3: Typical zones of a salt marsh in the Gulf of Maine. In Wells NERR marshes, the low marsh zone is a narrow band located along creek and channel edges. Figure by Ethan Nedeau, Biodrawversity.

shoreline. In fact, half of the marshes in Maine are less than half an acre in size. In her doctoral dissertation, Pamela Morgan investigated how the functions in these smaller fringing marshes compare to the large meadow marshes. She found that while fringing marshes had less organic matter and plant species diversity than meadow marshes, the two marsh types had similar productivity, amount of sediment trapping, and wave buffering—indicating that fringing marshes effectively perform many important ecosystem services (Morgan 2000).

Biogeographic Patterns

Northern New England marshes at Wells NERR have served as an important comparative community in numerous studies examining biogeographic variation in species interactions. Bertness and Ewanchuk compared the direction of species interactions (positive or negative) between marsh plants and found that in marshes of southern New England, species interactions were generally positive, as plants benefited from growing with neighbors that buffered hypersalinities. However, species interactions in northern New England were generally neutral or competitive, since salinities never reached high enough levels to be overly stressful (Bertness and Ewanchuk 2002). Pennings and colleagues have investigated whether consumer-prey interactions are more intense and prey defenses better developed at lower latitudes, using salt marshes as model systems. In a series of studies using sites in Wells NERR, they found that plants in northern New England were consistently more palatable to marsh consumers than southern plants (Pennings *et al*. 2001). Differences in palatability were due to variation in plant traits including toughness, palatability of secondary compounds, and nitrogen content (Siska *et al*. 2002) and these traits remain even when grown in common environmental conditions, meaning they are hardwired and not induced by growth conditions (Salgado and Pennings 2005). These studies have been integral to understanding how important species interactions that drive community dynamics vary across latitudinal and environmental conditions.

Salt Marsh Restoration

Salt marshes are exceedingly important coastal habitats that provide many critical ecosystem services. Marshes buffer shorelines from coastal erosion and storm surges, they provide nursery and feeding grounds for fisheries and wildlife and filter upland pollutants and nutrient from marine systems. Despite their value, marshes have been heavily impacted by humans. Early colonists in New

England created berms, dikes, and tidegates to improve conditions for farming salt marsh hay. More recently road causeways and dams have lead to tidal restrictions of many coastal rivers and lead to impounded fresh marshes upriver of the restrictions. Recent efforts have been made to restore tidal flow to these choked estuaries which generally results in the return of salt marsh vegetation and associated fauna (Burdick *et al*. 1997, Boumans *et al*. 2002). However, there is concern over whether return of physical conditions associated with salt water flushing can lead to native plant reestablishment, particularly once aggressive invasives have become established (Konisky and Burdick 2004). Researchers at the Wells NERR have developed a monitoring protocol to apply consistently to tidal restoration projects in an effort to establish consensus on restoration success (Neckles *et al*. 2002, Konisky *et al*. 2006).

LOW SALINITY TIDAL MARSHES

As you travel upriver in southern Maine estuaries, marshes continue to occupy the intertidal environment, but salinities decline, eventually becoming fresh water. Across this estuarine gradient marshes vary from salt, brackish, oligohaline (low salinity), to tidal freshwater. While all of these marshes receive tides twice daily, the variation in salinity and sulfide from marine sources drive variation in plant communities. Much less research has been conducted on low salinity tidal marshes of New England; however, research at Wells NERR is beginning to address this gap. Low salinity tidal marshes harbor unique plants and animals, are the first filter for upland pollutants, are highly productive and likely offer numerous ecosystem services that we are as of yet unaware of.

Low salinity tidal marshes (pictured) have greater plant productivity and species diversity than salt marshes. Brackish marshes tend to look superficially like salt marshes, but may have additional plant species such as

Autumn at the brackish side of Drake's Island marsh. This area was restored via the installation of a self-regulating tidegate. Cattails (Typha) are visible in the bottom left corner, indicating freshwater inputs to the upland border. Vegetative cover is dramatically different across the road on the other side of the culvert. Photo Erno Bonnebakker.

Above: a stand of invasive cattails. Below: Narrow-leaf cattail, Typha angustifolia, indicates a brackish wetland area. Photos Andrea Leonard.

Scirpus robustus, *Schoenoplectus tabernimontenii*, *Potentilla anserina*, *Atriplex patulata*, and *Typha angustifolia*. Tidal freshwater marshes are often dominated by entirely new plant species with very high species diversity within dominant zones. Common plants include *Carex stricta*, *Juncus balticus*, *Carex crinita*, *Eleocharis* sp., *Convolvulus sepium*, *Calamagrostis Canadensis*, *Spartina pectinata*, *Solidago sempervirens*, *Aster novi-belgii*, *Festuca rubra* and *Agrostis stolonifera* (see Table 8-1 for common names).

Species Distributions

Research in Rhode Island identified that the same processes driving species zonation across intertidal gradients in salt marshes drive species distribution patterns across estuarine salinity gradients. Plants found in oligohaline marshes cannot tolerate the physical conditions of salt marshes; however, salt marsh plants thrive in oligohaline marshes when native vegetation is removed but are typically competitively excluded from these habitats (Crain *et al*. 2004). Follow-up studies in southern Maine identified that the resources limiting salt marsh plants in fresh marshes vary depending on marsh zones: plants compete for nutrients in high diversity mixed plant zones and for light in *Typha angustifolia* stands (Crain in prep). Low salinity marshes are becoming increasingly dominated by *Typha* in high nutrient and disturbed areas and this causes major shifts in the community ecology of these marshes.

Studies in southern Maine estuaries identified that the limiting nutrient in coastal marshes varies across estuarine salinity gradients – salt and brackish marshes are nitrogen limited while oligohaline marshes are co-limited by nitrogen and phosphorus. Enrichment by both nutrients changes the plant composition in low salinity marshes, likely resulting in loss of species diversity given more time (Crain, in review). This study highlights the need to manage both nutrients in coastal estuaries to maintain healthy marshes of all salinities.

Some tidal freshwater marshes in Wells NERR are dominated by a tussock forming sedge, *Carex stricta*. This plant is an ecosystem engineer that alters the physical environment through the creation of mounds and subsequent retention of dead plant material, wrack, in inter-tussock spaces. All of the vegetation in these marshes is limited to living on top of the tussocks due to the suppression of vegetation by wrack in intertussock environments and additionally since tussock height provides a refuge from small mammal herbivores that forage in the intertussock areas (Crain and Bertness 2005). Tussocks thus exhibit scale-dependent inhibition where the negative effect of wrack is greatest at some distance from the tussock center,

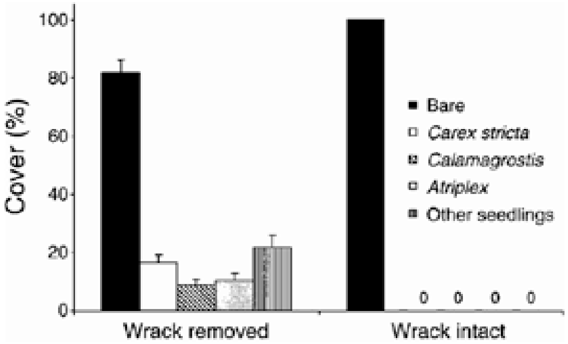


Figure 8-4: *Carex stricta* deposits wrack into inter-tussock spaces, restricting the growth of other plants. Bars show standard error (n =16) (Crain and Bertness 2005). Reprinted with permission from the Ecological Society of America.

Seed head of the common reed, Phragmites australis. Photo Andrea Leonard.

and this mechanism is responsible for generating regular spatial patterning of the vegetation (van de Koppel and Crain, in review).

We are starting to understand the unique physical and biological factors that structure vegetative communities in low salinity tidal marshes, knowledge essential to protecting these communities from the numerous human alterations impacting these systems.

HUMAN IMPACTS

Tidal restrictions change saltwater marshes to fresh impounded marshes with an accompanying shift in plant species, which often encourages invasion by monotypic stands of non-native plants.

Eutrophication, nutrient runoff from development or other watershed sources, shifts plant species interactions, reduces diversity and favors invasive plants. Both nitrogen and phosphorus are important in Wells NERR marshes. Invasive species such as *Phragmites* (see photo) and narrow-leaved cattail in the early stages of invasion are facilitated by human activity, such as altered hydrology, fill, and disturbed marsh soils.

Sea-level rise increases waterlogging of the marsh platform and also brings salt water farther upriver.

Upland development can have a direct impact on the marsh or an indirect impact through runoff of freshwater with high nutrient and sediment loads.

REFERENCES

Bertness, M.D. 1991. Zonation of Spartina-patens and Spartina-alterniflora in a New- England Salt-Marsh. Ecology 72: 138-148.

Bertness, M.D. and A. Ellison. 1987. Determinants of pattern in a New England salt marsh plant community. Ecological Monographs 57: 129-147.

Bertness, M.D. and P.J. Ewanchuk. 2002. Latitudinal and climate-driven variation in the strength and nature of biological interactions in New England salt marshes. Oecologia 132: 392-401.

Bertness, M.D., G.H. Leonard, J.M. Levine, P.R. Schmidt and A.O. Ingraham. 1999. Testing the relative contribution of positive and negative interactions in rocky intertidal communities. Ecology 80: 2711-2726.

Boumans, R.M. J., D.M. Burdick and M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10: 543-555.

Burdick, D.M., M. Dionne, R. M.J. Boumans and F.T. Short. 1997. Ecological responses to tidal restorations of two northern New England salt marshes. Wetlands Ecology and Management 4: 129-144.

Crain, C.M. and N.D. Bertness. 2005. Community impacts of a tussock sedge: Is ecosystem engineering important in benign habitats? Ecology 86: 2695-2704.

Crain, C.M., B.R. Silliman, S.L. Bertness and M.D. Bertness. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. Ecology 85: 2539-2549.

Crain, C. Shifting nutrient limitation and eutrophication impacts in marsh vegetation across estuarine salinity gradients. Estuaries and Coasts. In press.

Ewanchuk, P.J. and M.D. Bertness. 2003. Recovery of a northern New England salt marsh plant community from winter icing. Oecologia 136: 616-626.

Ewanchuk, P.J. and M.D. Bertness. 2004a. Structure and organization of a northern New England salt marsh plant community. Journal of Ecology 92: 72-85.

Ewanchuk, P.J. and M.D. Bertness. 2004b. The role of waterlogging in maintaining forb pannes in northern New England salt marshes. Ecology 85: 1568-1574.

Fogel, B.N., C.M. Crain and M.D. Bertness. 2004. Community level engineering effects of *Triglochin maritima* (seaside arrowgrass) in a salt marsh in northern New England, USA. Journal of Ecology 92: 589-597.

Gerard, V.A. 1999. Positive interactions between cordgrass, *Spartina alterniflora*, and the brown alga, *Ascophyllum nodosum ecad scorpioide*s, in a mid-Atlantic coast salt marsh. Journal of Experimental Marine Biology and Ecology 239: 157-164.

Konisky, R.A. and D.M. Burdick. 2004. Effects of stressors on invasive and halophytic plants of New England salt marshes: A framework for predicting response to tidal restoration. Wetlands 24: 434-447.

Konisky, R.A., D.M. Burdick, M. Dionne and H.A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology 14(4): 516-525.

Mathieson, A.C. and C.J. Dawes. 2001. A muscoides-like *Fucus* from a Maine salt marsh: Its origin, ecology, and taxonomic implications. Rhodora 103: 172-201.

Mathieson, A.C., C.J. Dawes, M.L. Anderson and E.J. Hehre. 2001. Seaweeds of the Brave Boat Harbor salt marsh and adjacent open coast of southern Maine. Rhodora 103: 1-46.

Morgan, P. 2000. Functions and values of salt marshes in northern New England: A comparison of fringing marshes and meadow marshes. University of New Hampshire.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum and E. Hutchins. 2002. A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales. Restoration Ecology 10: 556-563.

Nelson, B.W. and L.K. Fink. 1980. Geological and botanical features of sand beach systems in Maine. Planning Report No. 54. Maine Critical Areas Program Maine State Planning Office, Augusta, ME 169 pp.

Pennings, S.C., E.L. Siska and M.D. Bertness. 2001. Latitudinal differences in plant palatability in Atlantic coast salt marshes. Ecology 82: 1344-1359.

Salgado, C.S. and S.C. Pennings. 2005. Latitudinal variation in palatability of salt-marsh plants: Are differences constitutive? Ecology 86: 1571-1579.

Short, F.T. 1992. Declines of eelgrass in estuarine reserves along the east coast, U.S.A: problems of pollution and disease; and management of eelgrass meadows in East Coast research reserves. NOAA NOS Sanctuaries and Reserves Division, Silver Spring, MD. 112 pp.

Siska, E.L., S.C. Pennings, T.L. Buck and M.D. Hanisak. 2002. Latitudinal variation in palatability of salt-marsh plants: Which traits are responsible? Ecology 83: 3369-3381.

Theodose, T.A. and J. Martin. 2003. Microclimate and substrate quality controls on nitrogen mineralization in a New England high salt marsh. Plant Ecology 167: 213-221.

Theodose, T.A. and J.B. Roths. 1999. Variation in nutrient availability and plant species diversity across forb and graminoid zones of a Northern New England high salt marsh. Plant Ecology 143: 219-228.

van der Koppel, J. and C.M. Crain. *In press.* Scale-dependent positive and negative interactions lead to regular spatial patterning in marsh vegetation. The American Naturalist.

Table 8-1: Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
Basidiomycota (Club Fungi)	Agaricales	Shaggy Mane Mushroom	*Coprinus comatus*
		Vermilion Hygrophorus	*Hygrophorus* sp.
		Shield Lepiota	*Lepiota clypeolaria*
	Cantharellales	Coral Mushroom	*Clavaria* sp.
		Yellow Coral Mushroom	*Clavariadelphus* sp.
	Lycoperdales	Beautiful Puffball	*Lycoperdon pulcherrimum*
		Pear-Shaped Puffball	*Lycoperdon pyriforme*
	Phallales	Earth Star	*Geaster hygrometricus*
	Polyporales	Rusty Hoof Fungus, Tinder Fungus	*Fomes fomentarius*
		Artist's Fungus	*Ganoderma applanatum*
		Cinnabar Polypore	*Polypore sanguineus*
	Tremellales	Candied Red Jelly Fungus	*Phlogiotis helvelloides*
Magnoilaphyta (Flowering Plants)	Adoxaceae	Common Elder	*Sambucus canadensis*
		Arrowwood	*Viburnum dentatum v. lucidum (V. recognitum)*
		Hobblebush	*Viburnum lantanoides (V. alnifolium)*
		Nannyberry	*Vibernum lentago*
		Wild Raisin	*Viburnum nudum v. cassinoides (V. cassinoides)*
	Amaranthaceae	Orach	*Atriplex glabriuscula*
		Spearscale	*Atriplex patula*
		Pigweed	*Chenopodium album (C. lanceolatum)*
		Narrow-Leaved Goosefoot	*Chenopodium leptophyllum*
		Coast Blite	*Chenopodium rubrum*
		Dwarf Glasswort	*Salicornia bigelovii*
		Glasswort	*Salicornia depressa(S. europaea, S. virginica)*
		Woody Glasswort	*Salicornia maritima (S. europaea* var. *prostrata)*
		Common Saltwort	*Salsola kali*
		Southern Sea-Blite	*Sueda linearis (Dondia l.)*
		White Sea-Blite	*Sueda maritima (Dondia m.)*
	Anacardiacea	Poison Ivy	*Toxicodendron radicans (Rhus radicans)*
	Apiaceae	Alexanders Or Angelica	*Angelica atropurpurea*
		Sea Coast Angelica	*Angelica lucida (Coelopleurum l.)*
		Wild Sarsaparilla	*Aralia nudicaulis*
		Common Water-Hemlock	*Cicuta maculata*
		Queen Anne's Lace	*Daucus carota*
		Marsh Pennywort	*Hydrocotyle americana*
		Dwarf Ginseng	*Panax trifolius*
		Water-Parsnip	*Sium suave*
	Apocynaceae	Tall Milkweed	*Asclepias exaltata*
		Swamp Milkweed	*Asclepias incarnata*
		Purple Milkweed	*Asclepias purpurascens*
		Common Milkweed	*Asclepias syriaca*
	Aquifoliaceae	Smooth Winterberry	*Ilex laevigata*
		Winterberry	*Ilex verticillata*
		Mountain Holly	*Nemopanthus mucronatus (N. fascicularis)*
	Araceae	Jack-In-The-Pulpit	*Arisaema triphyllulm (A. atrorubens* and *A. stewardsonii)*
		Duckweed	*Lemna* sp.
		Skunk Cabbage	*Symplocarpus foetidus (Spathyema f.)*
	Asteraceae	Yarrow	*Achillea millefolium*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Common Ragweed	*Ambrosia artemisiifolia*
		Pearly Everlasting	*Anaphalis margaritacea*
		Smaller Pussytoes	*Antennaria howellii (A. h.* ssp. *neodioica)*
		Plantain-Leaved Pussytoes	*Antennaria plantaginifolia*
		Common Burdock	*Arctium minus (Lappa minor)*
		Canadian Wormwood	*Artemisia campestris* ssp. *caudata (A. caudata)*
		Dusty Miller	*Artemisia stellariana*
		White Wood Aster	*Aster divaricatus (Eurybia diverticata)*
		Bushy Aster	*Aster dumosus*
		Arrow-Leaved Aster	*Aster sagittifolius*
		Perennial Salt marsh Aster	*Aster tenuifolius*
		Blake's Aster	*Aster x blakei*
		Groundsel Tree	*Baccharis halimifolia*
		Purple Stem Beggar Ticks	*Bidens connata*
		Devil's Beggar Ticks	*Bidens frondosa*
		Canada Thistle	*Cirsium arvense*
		Pasture Thistle	*Cirsium pumilum*
		Lance-Leaved Coreopsis	*Coreopsis lanceolata*
		Smooth Hawksbeard	*Crepis capillaris*
		Flat-Topped White Aster	*Doellingeria umbellata (Aster umbellatus)*
		Pilewort	*Erechtites hieraciifolia*
		Daisy Fleabane	*Erigeron anuus*
		Rough Fleabane	*Erigeron strigosus*
		Three-Nerved Joe-Pye Weed	*Eupatorium dubium*
		Spotted Joe-Pye Weed	*Eupatorium maculatum*
		Boneset	*Eupatorium perfoliatum*
		Grass-Leaved Goldenrod	*Euthamia graminifolia (Solidago g.)*
		Slender-Leaved Goldenrod	*Euthamia tenuifolia (Solidago t.)*
		Low Cudweed	*Gnaphalium uliginosum*
		Orange Hawkweed	*Hieracium auranticum*
		Yellow Hawkweed	*Hieracium caespitosum (H. pratense)*
		Canada Hawkweed	*Hieracium canadense*
		Mouse Ear Hawkweed	*Hieracium pilosella*
		Mouse Ear Hawkweed	*Hieracium x flagellare*
		Stiff Aster	*Ionactis linariifolius (Aster liariifolius)*
		Cynthia	*Krigia biflora*
		Virginia Dwarf-Dandelion	*Krigia virginica*
		Tall Blue Lettuce	*Lactuca biennis (L. spicata)*
		Fall-Dandelion	*Leontodon autumnalis*
		Ox-Eye Daisy	*Leucanthemum vulgare (Chrysanthemum leucanthemum)*
		Northern Blazing Star	*Liatris scariosa v. novae-angliae (L. borealis)*
		Whorled Aster	*Oclemena acuminata (Aster acuminatus)*
		Gall Of The Earth	*Prenanthes trifoliolata*
		Fragrant Cudweed	*Pseudognaphalium obtusifolium (Gnaphalium o.)*
		Clammy Cudweed	*Pseudognaphalium viscosum (Gnaphalium macounii.)*
		Black-Eyed Susan	*Rudbeckia hirta (R. serotina)*
		Forest Goldenrod	*Soldiago arguta*
		Silverrod	*Solidago bicolor*
		Canada Goldenrod	*Solidago canadensis*
		Smooth Goldenrod	*Solidago gigantea*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Early Goldenrod	*Solidago juncea*
		Gray Goldenrod	*Solidago nemoralis*
		Rough-Leaved Goldenrod	*Solidago patula*
		Downy Goldenrod	*Solidago puberula*
		Rough-Stemmed Goldenrod	*Solidago rugosa*
		Seaside Goldenrod	*Solidago sempervirens*
		Elm-Leaved Goldenrod	*Solidago ulmifolia*
		Field Sow-Thistle	*Sonchus arvensis*
		Purple-Stemmed Aster	*Symphyotrichum puniceum (Aster puniceus)*
		Heart-Leaved Aster	*Symphyotrichum cordifolium (Aster cordifolius)*
		Calico Aster	*Symphyotrichum lateriflorum (Aster lateriflorus)*
		New England Aster	*Symphyotrichum novae-angliae (Aster novae-angilae)*
		New York Aster	*Symphyotrichum novi-belgii (Aster novi-belgii)*
		Dandelion	*Taraxacum officinale (T. latilobum)*
		Common Cocklebur	*Xanthium strumarium v. canadense (X. echinatum)*
	Balsaminaceae	Orange Touch-Me-Not	*Impatiens capensis (I. Biflora)*
	Berberidacea	American Barberry	*Berberis canadensis*
		Japanese Barberry	*Berberis thunbergii*
		Common Barberry	*Berberis vulgaris*
		Blue Cohosh	*Caulophyllum thalictroides*
	Betulaceae	Speckled Alder	*Alnus incana* ssp. *rugosa (A. rugosa)*
		Yellow Birch	*Betula alleghaniensis (B. lutea)*
		Paper Or White Birch	*Betula papyrifera*
		Gray Birch	*Betula populifolia*
		Beaked Hazelnut	*Corylus cornuta*
	Brassicaceae	Yellow Rocket	*Barbarea vulgaris (B. barbarea)*
		Hoary Alyssum	*Berteroa incana*
		Field Mustard, Bird's Rape	*Brassica rapa*
		Sea Rocket	*Cakile edentula*
		Shepherd's Purse	*Capsella bursa-pastoris (Bursa b.)*
		Cuckoo Flower	*Cardamine pratensis*
		Whitlow Grass	*Draba verna*
		Wormseed-Mustard	*Erysimum cheiranthoides (Cheirinia c.)*
		Wild Radish	*Raphanus raphanistrum*
		Watercress	*Rorippa nasturtium-aquaticum (Nasturtium officinale)*
		Hedge-Mustard	*Sisymbrium officinale (Erysimum o.)*
	Campanulaceae	Indian-Tobacco	*Lobelia inflata*
	Caprifoliaceae	Bush-Honeysuckle	*Diervilla lonicera*
		Fly Honeysuckle	*Lonicera canadensis*
		Japanese Honeysuckle	*Lonicera japonica*
		Tatarian Honeysuckle	*Lonicera tatarica*
		Mountain Fly Honeysuckle	*Lonicera villosa*
		Pink Honeysuckle	*Lonicera x bella*
	Caryophyllaceae	Thyme-Leaved Sandwort	*Arenaria serphyllifolia*
		Field Chickweed	*Cerastium arvense*
		Sea-Beach Sandwort	*Honckenya peploides* ssp. *robusta (Arenaria p.)*
		Ragged Robin	*Lychnis flos-cuculi*
		Grove Sandwort	*Moehringia lateriflora (Arenaria l.)*
		Bouncing Bet	*Saponaria officinalis*
		White Campion	*Silene latifolia* spp. Alba *(Lychnis alba)*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Night-Flowering Catchfly	*Silene noctiflora*
		Salt Marsh Sand Spurrey	*Spergularia salina (S. marina)*
		Common Stichwort	*Stellaria graminea (Alsine g.)*
		Common Chickweed	*Stellaria media (Alsine m.)*
	Celastraceae	Oriental Bittersweet	*Celastrus orbiculata*
	Cistaceae	Frostweed	*Helianthemum canadense (Crocanthemum c.)*
		Beach Heather	*Hudsonia tomentosa*
		Seaside Pinweed	*Lechea maritima*
	Clusiaceae	Pale St.Johnswort	*Hypericum ellipticum*
		Orange-Grass	*Hypericum gentianoides*
		Common St.Johnswort	*Hypericum perforatum*
		Spotted St. Johnswort	*Hypericum punctatum*
		Marsh St.Johnswort	*Triadenum virginicum (Hypericum v.)*
	Convallarianceae	Canada Mayflower	*Maianthemum canadense (Uniflium c.)*
		Star-Flowered False Solomon's Seal	*Maianthemum stellatum (Smilacina stellata)*
		Solomon's Seal	*Polygonatum pubescens*
		Hedge Bindweed	*Calystegia sepium (Convovulvus s.)*
		Common Dodder	*Cuscuta gronovii*
	Cornaceae	Silky Dogwood	*Cornus anomum*
		Bunchberry	*Cornus canadensis (Chamaepericlymenum canadense)*
	Crassulaceae	Garden Orpine	*Sedum telephium (S. purpureum)*
	Cucurbitaceae	Bur Cucumber	*Echinocystis lobata (Micrampelis l.)*
	Cupressaceae	Old Field Juniper	*Juniperus communis v. depressa*
		Red Cedar	*Juniperus virginiana*
	Cyperaceae	Salt marsh Bulrush	*Bolboschoenus maritimus* spp. *Paludosus (Scirpus m.)*
		Salt marsh Bulrush	*Bolboschoenus robustus (Scirpus r.)*
		Button Sedge	*Carex bullata*
		Fringed Sedge	*Carex crinita*
		White-Edged Sedge	*Carex debilis*
		Star Sedge	*Carex echinata (C. angustior)*
		Long Sedge	*Carex folliculata*
		Marsh Straw Sedge	*Carex hormathodes (C. straminea)*
		Interior Sedge	*Carex interior*
		Sedge	*Carex intumescens*
		Hop Sedge	*Carex lupilina*
		Sallow Sedge	*Carex lurida*
		Sedge	*Carex paleacea*
		Pointed Broom Sedge	*Carex scoparia*
		Seabeach Sedge	*Carex silicea*
		Tussock Sedge	*Carex stricta*
		Sedge	*Carex swanii*
		Sedge	*Carex tenera*
		Three Seeded Sedge	*Carex trisperma*
		Sedge	*Cyperus diandrus*
		Slender Cyperus Sedge	*Cyperus lupulinus* spp. *Macilentus (C. filiculmis)*
		Three-Way Sedge	*Dulichium arundinaceum*
		Spike-Rush	*Eleocharis halophila (E. uniglumis)*
		Creeping Spike-Rush	*Eleocharis palustris*
		Tawny Cotton Grass	*Eriophorum virginicum*
		Clustered Beak Rush	*Rhynchospora glomerata*
		Great Bullrush	*Schoenoplectus acutus (Scirpus a.)*
		Chair-Maker's-Rush	*Schoenoplectus pungens (Scirpus americanus)*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Softstem Bullrush	*Schoenoplectus tabernaemontanii (Scirpus validus)*
		Black Bullrush	*Scirpus atrovirens*
		Wool-Grass	*Scirpus cyperinus*
	Droseraceae	Round-Leaved Susndew	*Drosera rotundifolia*
	Equisetaceae	Field Horsetail	*Equisetum arvense*
		Water Horsetail	*Equisetum fluviatile*
		Meadow Horsetail	*Equisetum pratense*
		Woodland Horsetail	*Equisitum sylvaticum*
	Ericaceae	Bearberry	*Arctostaphylos uva-ursi*
		Leatherleaf	*Chamaedaphne calyculata*
		Broom Crowberry	*Corema conradii*
		Mayflower	*Epigaea repens*
		Wintergreen	*Gaultheria procumbens*
		Black Huckleberry	*Gaylussacia baccata*
		Dwarf Huckleberry	*Gaylussacia dumosa*
		Sheep Laurel	*Kalmia angustifolia*
		Maleberry	*Lyonia ligustrina (Xolisma l.)*
		Indian Pipe	*Monotropa uniflora*
		Round-Leaved Pyrola	*Pyrola americana (P. rotundifolia)*
		Rhodora	*Rhododendron canadense (Rhodora canadensis)*
		Lowbush Blueberry	*Vaccinium angustifolium*
		High-Bush Blueberry	*Vaccinium corymbosum (V. atrococcum)*
		American Cranberry	*Vaccinium macrocarpon*
		Velvet-Leaved Blueberry	*Vaccinium myrtilloides (V. canadense)*
		Small Cranberry	*Vaccinium oxycoccos*
	Euphorbiaceae	Seaside Spurge	*Chamaesyce polygonifolia (Euphorbia p.)*
	Fabaceae	Beach-Pea	*Lathyrus japonicus*
		Lupine	*Lupinus polyphyllus*
		Alfalfa	*Medicago sativa*
		Rabbit-Foot Clover	*Trifolium arvense*
		Yellow Clover, Palmate Hop Clover	*Trifolium aureum (T. agrarium)*
		Little Hop Clover	*Trifolium dubium*
		Alsike Clover	*Trifolium hybridum*
		Red Clover	*Trifolium pratense*
		White Clover	*Trifolium repens*
		Cow Vetch	*Vicia cracca*
		White Oak	*Quercus alba*
		Red Oak	*Quercus rubra (Q. borealis)*
	Gentianaceae	Yellow Bartonia	*Bartonia virginica*
	Geraniaceae	Bicknell's Wild Geranium	*Geranium bicknellii*
		Wild Geranium	*Geranium maculatum*
	Grossulariaceae	Bristly Gooseberry	*Ribes hirtellum*
	Hamamelidaceae	Witch-Hazel	*Hamamelis virginiana*
	Iridaceae	Slender Blue Flag	*Iris prismatica*
		Northern Blue Flag	*Iris versicolor*
		Blue-Eyed Grass	*Sisyrinchium montanum*
	Juglandaceae	Shagbark Hickory	*Carya ovata*
	Juncacaee	Sharp-Fruited Rush	*Juncus acuminatus*
		Wire Rush	*Juncus articus v. balticus (Juncus articus v. littoralis)*
		Canada Rush	*Juncus canadensis*
		Soft Rush	*Juncus effusus*
		Black Grass	*Juncus gerardii*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Greene's Rush	*Juncus greenei*
		Grass-Leaved Rush	*Juncus marginatus*
		Path Rush	*Juncus tenuis*
	Juncaginaceae	Seaside Arrowgrass	*Triglochin maritimum*
	Lamiaceae	Hairy Wood Mint	*Blephilia hirsuta*
		American Water-Horehound	*Lycopus americanus*
		Northern Water-Horehound	*Lycopus uniflorus*
		Virginia Water-Horehound	*Lycopus virginicus*
		Wild Mint	*Mentha arvensis*
		Heal-All	*Prunella vulgaris*
		Marsh Skullcap	*Scutellaria galericulata (S. epilobiifolia)*
		Mad Dog Skullcap	*Scutellaria laterifolia*
		American Germander	*Teucrium canadense*
		Blue Curls	*Trichostema dichotomum*
	Lauraceae	Sassafras	*Sassifras albidum*
	Liliaceae	Trout Lily	*Erythronium americanum*
		Wood Lily	*Lilium philadelphicum (L. tigrinum)*
		Indian Cucumberroot	*Medeola virginiana*
	Linaceae	Common Flax	*Linum usitatissimum*
	Lycopodiaceae	Northern Running-Pine	*Diphrasiastrum complanatum (Lycopodium c.)*
		Shining Club-Moss	*Huperzia lucidula (Lycopodium lucidulum)*
		Bristly Club-Moss	*Lycopodium annotinum*
		Ground-Pine	*Lycopodium obscurum*
	Melanthiaceae	Indian Poke , False Hellebore	*Veratrum viride*
	Myricaceae	Sweetfern	*Comptonia peregrina (Myrica aspleniifolia)*
		Sweet Gale	*Myrica gale*
		Bayberry	*Myrica pensylvanica*
	Oleaceae	White Ash	*Fraxinus americana*
		Black Ash	*Fraxinus nigra*
		Lilac	*Syringa vulgaris*
	Onagraceae	Fireweed	*Epilobium angustifolium (Chamaenerion angustifolium)*
		American Willow-Herb	*Epilobium ciliatum*
		Narrow-Leaved Willowherb	*Epilobium leptophyllum*
		Common Evening-Primrose	*Oenothera biennis (O. muricata)*
		Small-Flowered Evening-Primrose	*Oenothera parviflora (O. cruciata)*
	Orchidaceae	Arethusa	*Arethusa bulbosa*
		Grass Pink	*Calopogon tuberosus (C.puchellus)*
		Early Coralroot	*Corallorhiza trifida*
		Pink Ladys-Slipper	*Cypripedium acaule (Frissipes acaulis)*
		Green Woodland Orchid	*Plantanthera clavellata (Habenaria c.)*
		Pale Green Orchid	*Plantanthera flava (Habenaria f.)*
		Ragged Orchid	*Plantanthera lacera (Habenaria l.)*
		Small Purple Fringed Orchid	*Plantanthera psycodes (Habenaria p.)*
		Rose Pogonia	*Pogonia ophioglossoides*
		Nodding Ladies Tresses	*Spiranthes cernua (Ibidium cenuum)*
	Orobanchaceae	Seaside Gerardia	*Agalinus maritima (Gerardia m.)*
		Purple Gerardia	*Agalinus pauperacula (Agalinus purpurea)*
		Cowwheat	*Melampyrum lineare*
		Wood-Betony	*Pedicularis canadensis*
		Yellow Rattle	*Rhinanthus minor (R. crista-galli)*
	Oxalidaceae	Common Wood Sorrel	*Oxalis montana (O. acetosella)*
		Common Yellow Wood-Sorrel	*Oxalis stricta (O. europaea)*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
	Plumbaginaceae	Sea Lavender	*Limonium carolinianum (L. nashii)*
	Poaceae	Rhode Island Bentgrass	*Agrostis capillaris (A. tenuis)*
		Redtop	*Agrostis gigantea (A. alba)*
		Autumn Bentgrass	*Agrostis perennans*
		Hairgrass	*Agrostis scabra*
		Beach Grass	*Ammophila breviligulata*
		Sweet Vernal Grass	*Anthoxanthum odoratum*
		Long-Awned Wood-Grass	*Brachyelytrum septentrionale (B. erectum)*
		Canada Blue-Joint	*Calamagrostis canadensis*
		Small Reedgrass	*Calamagrostis cinnoides*
		Orchard Grass	*Dactylis glomerata*
		Wavy Hairgrass	*Deschampsia flexuosa*
		Spike Grass	*Distilchis spicata*
		Witch Or Quack Grass	*Elymus repens (Elytrigia r.)*
		Sheep Fescue	*Festuca ovina*
		Red Fescue	*Festuca rubra*
		Rattlesnake Grass	*Glyceria canadensis (Panicularia c.)*
		Fowl Meadowgrass	*Glyceria striata (G. nervata)*
		Sweetgrass	*Hierochloe odorata*
		American Dunegrass	*Leymus mollis (Elymus arenarius)*
		Marsh Muhly	*Muhlenbergia glomerata (M. setosa)*
		Wooly Panic Grass	*Panicum acuminatum (Dichanthelium a.)*
		Witchgrass	*Panicum capillare*
		Starved Panic Grass	*Panicum depauperatum (Dichanthelium d.)*
		Panic Grass	*Panicum longifolium*
		Switchgrass	*Panicum virgatum v. spissum*
		Reed Canarygrass	*Phalaris arundinacea*
		Timothy	*Phleum pratense*
		Common Reed	*Phragmites australis (P. communis)*
		Canada Bluegrass	*Poa compressa*
		Fowl Meadowgrass	*Poa palustris (P. triflora)*
		Seaside Alkali-Grass	*Puccinellia maritima*
		Poor Grass	*Puccinellia tenella (P. paupercula)*
		Little Bluestem	*Schizachrium scoparium (Andropogon scoparius)*
		Knotroot Bristlegrass	*Setaria geniculata*
		Salt marsh Cordgrass	*Spartina alterniflora*
		Salt Hay	*Spartina patens*
		Fresh Water Cordgrass	*Spartina pectinata*
		Foxtail	*Setaria pumila (S. glauca)*
	Polygalaceae	Fringed Polygala, Gaywings	*Polygala paucifolia*
		Blood Milkwort	*Polygala sanguinea (P. viridescens)*
	Polygonaceae	Climbing False Buckwheat	*Fallopia scandens (Polygonum s.)*
		Halberd-Leaved Tearthumb	*Persicaria arifolia (Polygonum arifolium)*
		Common Smartweed	*Persicaria hydropiper (Polygonum h.)*
		Dock-Leaved Smartweed	*Persicaria lapthifolia (Polygonum lapthifolium)*
		Pennsylvania Smartweed	*Persicaria pensylvanica (Polygonum pensylvanicum)*
		Arrow-Leaved Tearthumb	*Persicaria sagittata (Polygonum sagittatum)*
		Jointweed	*Polygonella articulata*
		Prostrate Knotweed	*Polygonum aviculare*
		Sheep Sorrel	*Rumex acetosella*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Curly Dock	*Rumex crispus*
		Marsh Fern	*Thelypteris palustris v. pubescens (Dryopteris thelypteris v. p.)*
	Portulacaceae	Carolina Spring Beauty	*Claytonia caroliniana*
	Potomogetonaceae	Wigeon-Grass	*Ruppia maritima*
	Primulaceae	Sea Milkwort	*Glaux maritima*
		Whorled Loosestrife	*Lysimachia quadrifolia*
		Swamp Candles	*Lysimachia terrestris*
		Starflower	*Trientalis borealis (T. americana)*
	Ranunculaceae	Wood Anemone	*Anemone quinquefolia*
		Garden Columbine	*Aquilegia vulgaris*
		Virgin's Bower	*Clematis virginiana*
		Goldthread	*Coptis trifolia (C. groenlandica)*
		Common Buttercup	*Ranunculus acris*
		Seaside Crowfoot	*Ranunculus cymbalaria*
		Cursed Crowfoot	*Ranunculus sceleratus*
		Tall Meadowrue	*Thalictrum pubescens (T. polygamum)*
	Rosaceae	Downy Serviceberry	*Amelanchier arborea*
		Serviceberry	*Amelanchier arborea v. laevis*
		Eastern Serviceberry	*Amelanchier canadensis*
		Silverweed	*Argentina anserina (Potentilla a.)*
		Marsh-Potentilla	*Comarum palustre (Potentilla palustris)*
		Hawthorn	*Crategus* sp.
		Rattlebox	*Crotalaria sagittalis*
		Woodland Strawberry	*Fragaria vesca*
		Wild Strawberry	*Fragaria virginiana*
		Water Avens	*Geum rivale*
		Wild Apple	*Malus sylvestris (Pyrus s.)*
		Red Chokeberry	*Photinia arbutafolia (Pyrus a.)*
		Black Chokeberry	*Photinia melanocarpa (Pyrus m.)*
		Purple Chokeberry	*Photinia x floribunda (Pyrus f.)*
		Silvery Cinquefoil	*Potentilla argentea*
		Running Cinquefoil	*Potentilla canadensis (P. pumila)*
		Rough Cinquefoil	*Potentilla norvegica (P. monspeliensis)*
		Rough-Fruited Cinquefoil	*Potentilla recta*
		Old-Field Cinquefoil	*Potentilla simplex*
		Beach Plum	*Prunus maritima*
		Pin Or Fire Cherry	*Prunus pensylvanica*
		Sand Cherry	*Prunus pumila (P. p. v. susquehanae)*
		Black Cherry	*Prunus serotina*
		Chokecherry	*Prunus virginiana*
		Smooth Rose	*Rosa blanda*
		Pasture Rose	*Rosa carolina*
		Multiflora Rose	*Rosa multiflora*
		Bristly Rose	*Rosa nitida*
		Swamp Rose	*Rosa palustris*
		Rugosa Rose	*Rosa rugosa*
		Virginia Rose	*Rosa virginiana*
		Common Blackberry	*Rubus allegheniensis*
		Dewdrop	*Rubus dalibarda (Dalibarda repens)*
		Prickly Dewberry	*Rubus flagellaris*
		Swamp Dewberry	*Rubus hispidus*
		Red Raspberry	*Rubus idaeus*
		Black Raspberry	*Rubus occidentalis*
		Dwarf Raspberry	*Rubus pubescens*
		Three-Toothed Cinquefoil	*Sibbaldiopsis tridentata (Potentilla t.)*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Meadowsweet	*Spiraea alba v. latifolia (S. latifolia)*
		Steeplebush	*Spiraea tomentosa*
	Rubiaceae	White Bedstraw	*Galium mollugo (G. erectum)*
		Marsh Bedstraw	*Galium palustre*
		Bluets	*Houstonia caerulea (Hedyotis c.)*
		Partridgeberry	*Mitchella repens*
	Salicaceae	Quaking Aspen	*Populus tremuloides*
		Pussy Willow	*Salix discolor*
	Santalaceae	Bastard Toadflax	*Comandra umbellata (C. richardsiana)*
	Sapindaceae	Box Elder	*Acer negundo*
		Moosewood	*Acer pensylvanicum*
		Norway Maple	*Acer platanoides*
		Red Maple	*Acer rubrum*
	Scrophulariaceae	Common Mullein	*Verbascum thapsus*
	Smilacaceae	Carrion Flower	*Smilax herbacea (Nemexia h.)*
	Solnaceae	Bittersweet Nightshade	*Solanum dulcamara*
	Ttrilliaceae	Nodding Trillium	*Trillium cernuum*
	Typhaceae	Narrow-Leaved Cat-Tail	*Typha angustifolia*
		Common Cat-Tail	*Typha latifolia*
	Ulnaceae	Elm	*Ulmus* sp.
	Uvulariaceae	Clintonia	*Clintonia borealis*
		Wild Oats	*Uvularia sessilifolia*
	Verbenaceae	White Vervain	*Verbena utricifolia*
	Veronicaceae	White Turtlehead	*Chelone glabra*
		Butter And Eggs	*Linaria vulgaris (L. linaria)*
		Seaside Plantain	*Plantago maritima v. juncoides (P. juncoides)*
		English Plantain	*Plantago lanceolata (P. altissima)*
		Common Plantain	*Plantago major*
		Long-Leaved Speedwell	*Veronica longifolia*
		Commonn Speedwell	*Veronica officinalis*
		Thyme-Leaved Speedwell	*Veronica serpyllifolia*
	Violaceae	Common Blue Violet	*Viola affinis (V. papilionacea)*
		Marsh Blue Violet	*Viola cucullata (V. obliqua)*
		Wild White Violet	*Viola macloskeyi* ssp. *pallens (V. pallens)*
		Round-Leaved Violet	*Viola rotundifolia*
		Arrowhead Violet	*Viola sagittata (V. s. v. ovata)*
		Dooryard Violet	*Viola sororia (V. septentrionalis)*
	Vitaceae	Virginia Creeper	*Parthenocissus quinquefolia*
Coniferophyta (Conifers)	Pinaceae	Balsam Fir	*Abies balsamea*
		American Larch	*Larix laricina*
		Red Spruce	*Picea rubens*
		Red Pine	*Pinus resinosa*
		Pitch Pine	*Pinus rigida*
		White Pine	*Pinus strobus*
		Hemlock	*Tsuga canadensis*
Pteridophyta (Ferns)	Polypodiaceae	Lady Fern	*Athyrium filix-femina v. angustum*
		Hay-Scented Fern	*Dennstaedtia punctilobula*
		Spinulose Wood-Fern	*Dryopteris carthusiana (D. spinulosa)*
		Crested Fern	*Dryopteris cristata*
		Marginal Fern	*Dryopteris marginalis*
		Oak Fern	*Gymnocarpium dryopteris*
		Ostrich Fern	*Matteuccia struthiopteris v. pensylvanica*
		Sensitive Fern	*Onoclea sensibilis*

Table 8-1 (continued): Plants, fungi and algae found at Wells NERR.

Division	Order	Common Name	Scientific Name
		Long Beech Fern	*Phegopteris connectilus (Dryopteris phegopteris)*
		Bracken	*Pteridium aquilinum*
		New York Fern	*Thelypteris noveboracensis (Dryopteris n.)*
	Osmundaceae	Royal Fern	*Osmunda regalis (O. spectibilis)*
		Cinnamon Fern	*Osmunda cinnamomea*
		Interrupted Fern	*Osmunda claytonia*
Chrysophyta (Golden-brown Algae)	Chrysophyceae	Dictyochaceae	*Dictyocha* sp.
Pyrrophycophyta (Dinoflagellates)	Dinophyceae	Goniodomataceae	*Alexandrium tamarense*
		Ceratiaceae	*Ceratium fusus*
			Ceratium fusus
			Ceratium longipes
			Ceratium longpipes
		Gonyaulacaceae	*Gonyaulax spinifera*
		Calciodinellaceae	*Scrippsiella* sp.
		Dinophysiaceae	*Dinophysis acuminata*
			Dinophysis acuminata
			Dinophysis norvegica
			Dinophysis norvegica
		Gymnodiniaceae	*Gymnodinium* sp.
		Protoperidinaceae	*Protoperidinium* sp.
	Prorocentrales	Prorocentrum	*Prorocentrum micans*
Bacillariophyta (Diatoms)	Coscinodiscophyceae	Chaetocerotaceae	*Chaetoceros* sp.
			Chaetoceros socialis
			Cocinodiscus sp.
		Skeletonemaceae	*Skeletonema* sp.
		Melosiraceae	*Melosira* sp.
	Bacillariophyceae	Diploneidaceae	*Diploneis* sp.
			Eucampia sp.
		Pleurosigmataceae	*Gyrosigma* sp.
		Leptocylindraceae	*Leptocylindrus* sp.
		Naviculaceae	*Navicula* sp.
		Bacillariaceae	*Nitzschia* sp.
			Pseudo-nitzschia sp.
		Eupodiscaceae	*Odontella* sp.
	Fragilariophyceae	Licmophoraceae	*Licmophora*
		Thalassionemataceae	*Thalassionema* sp.
Phaeophyta (Brown Algae)	Fucaceae	Common Rockweed	*Fucus vesiculosis*
		Spiral Rockweed	*Fucus spiralis*
		Knotted Wrack	*Ascophyllum nodosum*
	Laminariaceae	Common Kelp	*Laminaria agardhii*
		Finger Kelp	*Laminaria digitata*
		Sea Colander Kelp	*Agarum cribrosum*
Chlorophyta (Green Algae)	Ulvaceae	Sea Lettuce	*Ulva lactuca*
		Green Hair Weed	*Chaetomorpha linum*
		Hollow Green Algae	*Enteromorpha intestinalis*
Rhodophyta (Red Algae)	Gigartinaceae	Irish Moss	*Chondrus crispus*
	Rhodomelaceae	Tubed Weed	*Polysiphonia lanosa*
		Encrusting Red Algae	*Lithothamnium* sp.
	Corallinaceae	Coral Weed	*Corallina officinalis*
	Ceramiaceae	Banded Weed	*Ceramium rubrum*
	Bangiaceae	Purple Laver	*Porphyra umbilicalis*

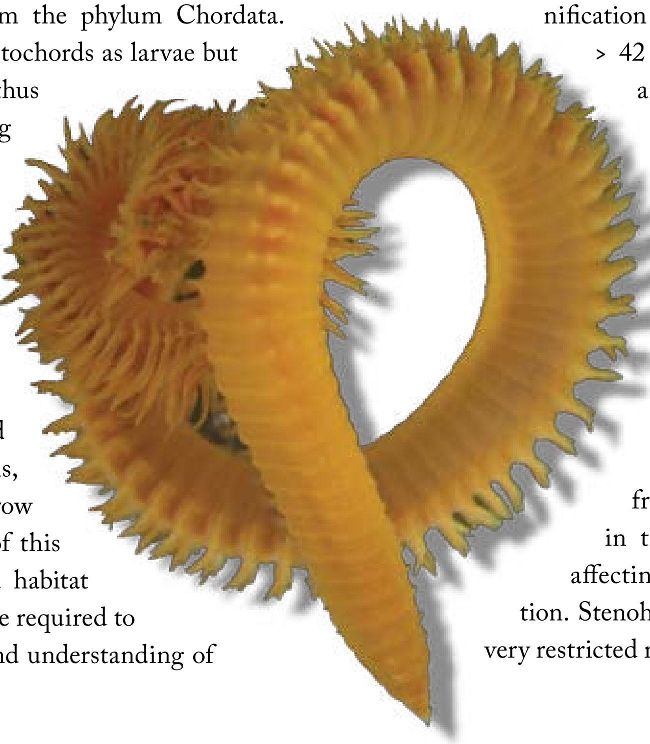
CHAPTER 9

Invertebrates

MEGAN TYRRELL

The marine and estuarine invertebrates are the most diverse group (at least at the phyla level) of organisms in the Wells NERR. There are approximately 14 phyla of marine and estuarine organisms in the Reserve boundaries or in the surrounding habitats. We have representatives from (in phylogenetic order): Protozoa, Porifera, Cnidaria, Platyhelminthes, Nemertea, Nematoda, Mollusca, Annelida, Sipunculida, Arthropoda, Bryozoa, Echinodermata and Hemichordata. In addition, we have tunicates (sea squirts), from the phylum Chordata. Tunicates have primitive notochords as larvae but lose them as adults, and thus are often considered along with invertebrates.

Marine invertebrates use their habitats in a wide variety of manners: they are suspended in the water column, live on and within the sediments, attach to hard surfaces or other organisms, and crawl, swim and burrow to move around. Because of this diversity in life forms and habitat use, a few key definitions are required to facilitate communication and understanding of marine and estuarine invertebrates. Epifauna are organisms that live on the substrate surface (see snails, pictured) or attached to another organism (i.e.,an anemone that is attached to a mussel shell). Infauna live within the substrate and are prominent in soft sediments such as sand and mud (i.e.,borrowing worms). Species that are incapable of moving as adults are sessile (e.g. a barnacle attached to a piling). Macroinvertebrate refers to organisms that are large enough to be observed without magnification while meiofauna (<1 mm but > 42 micrometers) are very small animals that live between sediment grains. There are many species of meiofauna, but because of their small size, many are likely remaining to be described. Finally, most invertebrate inhabitants of estuaries are euryhaline (can tolerate a relatively large range of salinities) because freshwater influx, especially in the spring, is a major factor affecting resident species composition. Stenohaline species, or those with a very restricted range of salinity tolerance, are



Littorina littorea, an example of epifauna commonly found at Wells NERR, both in vegetated marsh and sandy substrates. Photo by Susan Bickford.

likely only present in estuarine habitats during periods of stable salinities.

The invertebrate community of the Wells NERR marshes varies somewhat from that described for New England marshes by Pennings and Bertness (2001). We lack fiddler crabs (*Uca* spp.) that construct burrows and ribbed mussels (*Geukensia demissa*), whose byssal threads help to bind and stabilize sediments. Additionally, major grazing snail species such as the marsh periwinkle, *Littoraria irrorata*, and the marsh snail, *Melampus bidentatus* are absent, but the introduced common periwinkle, *Littorina littorea*, likely fulfills a very similar ecological role as these native snail species. Similarly, the blue crab, *Callinectes sapidus*, whose voracious predation pressure influences zonation and distribution of many invertebrates in southern marshes, is absent from the Reserve. Nevertheless, another introduced species, the green crab, *Carcinus maenas*, likely has a similar influence over the distribution and abundance of benthic invertebrates at the Reserve and other Gulf of Maine marshes.

CHARACTERISTIC MARINE AND ESTUARINE INVERTEBRATES

The following are brief descriptions and highlights of the invertebrates that are commonly found in the various habitat types that are represented at the Wells NERR. Not all of the invertebrates that occur within each habitat type are described and many of the invertebrates occur within more than one habitat type. Those species that are described for each section are putatively those that are most likely to be encountered by a casual observer.

Salt Marsh

The most conspicuous salt marsh invertebrates are the gastropods, *Littorina littorea*, *L. saxatilis*, and the amphipods, *Orchestia grillus* and *Orchestia platensis*. These species can be found among lower salt marsh vegetation at all stages of the tidal cycle. Amphipods (pictured) are mostly detritivores and are most commonly found in the thick mat of algal ecads in the low marsh zone (see photo in Ch. 8). These ecads provide protection from desiccation and predators. *Littorinid gastropods* are distributed throughout the lower marsh and are either grazing the microalgae that grows epiphytically on smooth cordgrass or on the substrate or in the algal ecads. The only native periwinkle in marsh habitats is the rough periwinkle, *Littorina saxatilis* (see photo). There is strong potential for competitive overlap between these two closely related snail species. In rocky intertidal habitats, *L. littorea* has been implicated in suppressing the growth rates of *L. saxatilis* (Behrens Yamada and Mansour 1987).

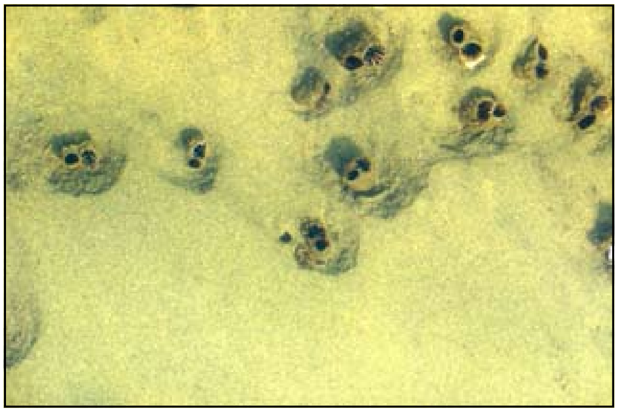
Invertebrate species that utilize salt marsh habitats while they are submerged include the green crab, *Carcinus maenas,* and the grass shrimp *Palaemonetes pugio,* and the sand shrimp, *Crangon septemspinosa*. All three of these decapod crustaceans have predatory and scavenging feeding behaviors, but of the three, the green crab is the most influential predator because of its large size and high biomass in marshes.

A variety of other species, including annelids and bivalves, occupy sediments of salt marshes, but are less prominent than the previously mentioned species. The clamworm, (*Neanthes virens*) is typically thought of as a mudflat predator, but it also lives in the sediments of vegetated marshes. This polychaete likely influences the abundance of many smaller species including other polychaetes such as *Nephtys incisa* and tubificid oligochaete worms (Commito and Schrader 1985).

There are four families of fly larvae that are common in salt marshes, especially in the upper fringes of the marsh: (Chironomidae, Ceratopogonidae [e.g. *Culicoides sp*.], Dolichopodidae, Phychodidae). Mites (Acarina), leaf hoppers (Delphasidae), grasshoppers (Orthoptera), jumping spiders (Salticidae) and wolf spiders (*Lycosa* sp.) are also common in salt marshes of this region. Most insects cannot tolerate submergence in salt water so many live at the upper fringe of tidal influence in the high marsh and upland border plant zone. The non-flying insects, such as spiders, generally migrate up and down the grass blades to avoid being submerged with incoming tides. Some insect larvae have adaptations to deal with salt water inundation including breathing tubes (e.g. Dipterans) and salt excretion glands (Homopterans).

Mudflats

Macroinvertebrate fauna typical of intertidal mud flats in southern Maine include: the soft-shell clam, *Mya arenaria*, the Baltic Macoma clam, *Macoma balthica*, the clam worm, *Neanthes virens*, the bloodworm, *Glycera dibranchiata*, the mud snail, *Illyanassa obsoleta* (pictured), the common periwinkle, *Littorina littorea*, and the amphipod, *Corophium* sp. *Mya* is a filter feeding clam that accesses water column particles with its long siphon (pictured); this species cannot close its fragile shell completely over its body and thus is extremely vulnerable if dislodged from the sediments. Baltic Macoma (*Macoma balthica*) is unlike many of the other bivalves in our region in that it is not a filter feeder but obtains



Siphons of soft-shell clams can be seen on the surface of soft sediments. Photo Michele Dionne.

Amphipods are a common epibenthic invertebrate at the Reserve. Photo Jeremy Miller.

Littorina saxatilis. Photo Megan Tyrell.

food particles by sweeping the sediments with its long inhalant siphon. *Neanthes* is an omnivore, in addition to algae, it can readily consume other common mudflat inhabitants such as *Corophium volutator* and another predatory polychaete, *Nepthys incisa*. The bloodworm, *Glycera dibranchiata*, earns its common name from the blood that can be seen through its body wall. Both *Neanthes* and *Glycera* are harvested for use as bait. The nemertean or ribbon worms (e.g. *Cerebratulus luridas*) are predatory, and can consume *Mya arenaria* and worms. *Littorina littorea* is an introduced species that is native to northwest Europe. It has been in the Gulf of Maine for approximately 150 years and has been blamed for displacing the mud snail from its optimal habitats and for consuming mud snail eggs (Brenchley and Carlton 1983). The mud snail is an herbivorous snail that grazes benthic diatoms on mudflats; its conspicuous periodic aggregations in tidal streams are for reproduction. *Corophium* is a tube-dwelling amphipod that is both a deposit and filter feeder. Shorebirds consume *Corophium* when they stop in mudflats to replenish energy during migration. Many of the invertebrates that utilize intertidal mudflats can also inhabit the shallow subtidal zone but the higher predation pressure of continually submerged habitats likely limits their distributions to more physically stressful, but safer, intertidal habitats.

Other burrowing invertebrates that inhabit mudflats in our region include: quahog clams (*Mercenaria mercenaria*), gem clams (*Gemma gemma*) (pictured) and various species of crustaceans (isopods [e.g. *Edotea triloba*], amphipods and cumaceans). The burrowing infauna that inhabit muddy bottoms contribute to nutrient cycling and their activities keep the top couple of centimeters of sediments from becoming anoxic (oxygen deprived), which benefits other muddy bottom inhabitants (see Ch. 7 for a more thorough explanation of these phenomena). In addition, the fecal pellets produced by some infaunal species help to consolidate and stabilize sediments which effectively changes the sediment grain size.

Ilyanassa. Photo Michael D. Haas.

A gem clam (gemma gemma) with hydrozoans attached to its back. Photo Jeremy Miller.

Sandy Substrates

The sandy substrates of the Wells NERR have not been subject to the same level of research as salt marsh and mudflat habitats (see below), therefore, we know less about their invertebrate communities. Generally, the species diversity of sandy substrates is lower than that of other habitat types because sand occurs in highly dynamic environments, which often lead to physically stressful conditions for sessile or swimming species. Although there have been no concerted research efforts aimed at documenting the sandy habitat invertebrates of the Wells NERR, observations of the beach's wrack line provide some indication of the local inhabitants.

Molluscs, including jingle shells (*Anomia simplex*), blue mussels (*Mytilus edulis*), quahog clams (*Mercenaria mercenaria*), surf clams (*Spisula solidissima*), razor clams (*Siliqua costata*) and jackknife clams (*Ensis directus*) are common in the wrack line. All of these species generally live buried beneath the sandy sediments except *Mytilus edulis*, which only occurs in sandy habitats if it is attached to the shell of another organism via its anchoring byssal threads. Moon snails (*Lunatia* sp.) hunt for their prey beneath a thin layer of sand. Their distinctive egg cases (sand covered rubbery collars) are often encountered on the beach. Crustaceans that are encountered in the wrack line include various species of isopods and amphipods as well as carapaces from green and Cancer crabs. Live amphipods from the family Talitridae (beach hoppers, e.g., *Orchestia platensis*) graze on decaying plant and animal material in the wrack line and digging amphipods (e.g. *Haustorius canadensis*) inhabit the surf zone and shallow subtidal zone. Finally, sand dollars (e.g. *Echinarachnius parma*) and great piddock clams (*Zirfaea crispata*) are occasionally deposited in the wrack line after big storms.

Water Column

Many marine and estuarine invertebrates have a planktonic larval stage and therefore most species spend a portion of their life cycle in water column habitats. Having a planktonic dispersal stage allows those invertebrates that are sessile or have limited mobility as adults (e.g. clams, snails, anemones) to colonize new areas after a disturbance or local extinction. Species that are only planktonic for a short time are called meroplankton and those that spend their entire life cycle in the plankton are called holoplankton. Common invertebrate meroplankton species of the Reserve include soft-shell clams (*Mya arenaria*), common periwinkle (*Littorina littorea*), green crabs (*Carcinus maenas*) (pictured) and the clamworm (*Neanthes* sp.). The larval stages of these four species, as well as larval stages of many other marsh inhabitants, were documented in a zooplankton survey in the Webhannet and Little River embayments (see Table 9-1). There have been no studies specifically focused on documenting large holoplankton of the Reserve, but ctenophores (e.g. the sea gooseberry, *Pleurobrachia pileus*) are occasionally recovered in plankton tows at Wells Harbor.

A diversity of organisms can be found in a fouling community. Here, colonial, solitary, upright, and prostrate creatures are attached to a marble substrate. Photo Megan Tyrell.

FOULING COMMUNITIES

Fouling organisms are so called because they attach to structures that humans place in the water, such as docks, piers, buoys, boats, etc. (pictured). Invertebrates compose the vast majority of fouling species, with blue mussels (*Mytilus edulis*; pictured), hydroids (e.g. *Tubularia* sp.), bryozoans (e.g. *Bugula turrita*), tunicates (e.g. *Botrylloides violaceus*) and sponges (e.g. *Halichondria panicea*) as common constituents of fouling communities in southern Maine. Perhaps not coincidentally, many of the species that are found in fouling communities are introduced species. In addition to the most common

A fouling community at the Wells Harbor. Photo Hannah Wilhelm.

route of species introductions in the marine and estuarine environment (being transported in ballast water as larvae), adult fouling organisms can be dispersed to new locations when they are attached to boat hulls. A recent study of fouling organisms in Wells Harbor revealed that two introduced tunicate species, *Botrylloides violaceus* and *Botryllus schlosseri,* were able to colonize a wide variety of artificial and natural substrate types. As time progressed, these introduced tunicates increased disproportionately on the artificial substrate types, at the expense of native species, which declined (Tyrrell and Byers, in press).

HUMAN INFLUENCES

Introduced Marine Invertebrates

As previously mentioned, two of the most conspicuous marine invertebrates of the Wells NERR are not native to this region. The green crab, *Carcinus maenas*, and the common periwinkle, *Littorina littorea*, both originated in Europe and were brought to our region by humans. Both species have high abundance and biomass in salt marsh habitats and there is virtually no chance of eradicating them from the Reserve or from the Gulf of Maine in general. Several research projects in the Wells NERR are seeking to clarify the impacts of grazing by the common periwinkle and predation by the green crab as well as its competitive interactions with native species. A third introduced species, the European oyster (*Ostrea edulis*) occurs in the Webhannet River. In the 1950's the Maine Department of Marine Resources deliberately introduced this species to several estuaries on the coast. The European oyster did not thrive in the Webhannet River and currently only a small population can be encountered in one section of the river channel.

As previously mentioned, introduced species are prominent components of fouling communities. The introduced tunicates, *Botrylloides violaceus* and *Botryllus schlosseri*, were the second and third most abundant species in a fouling community study conducted at Wells Harbor (Tyrrell and Byers, in press). Another prominent introduced species, the lacy crust bryozoan, *Membranipora membranacea*, also settled on the substrates in the experiment. This species is most notorious for its tendency to settle on macroalgae, especially kelp, but it can colonize a wide variety of surfaces. Four other cryptogenic (origin uncertain) species were found in the fouling experiment; they included two other encrusting bryozoans, *Cryptosula pallasiana* and *Electra pilosa*, as well as the creeping bryozoan, *Bowerbankia gracilis,* and feathery hydroids of the genus *Campanularia*.

Harvesting

Harvesting of invertebrates for commercial purposes is not allowed within the confines of Wells NERR (boundaries end with the vegetated edge of the marsh). Clam flats are managed by the town and the Maine Department of Marine Resources, and a limited harvest of soft-shell clams and clam worms is permitted. Clammers and worm diggers are required to use specific hand-tools for their harvesting efforts, and obtain appropriate licenses. Trampling and bioturbation caused by the digging likely has negative implications for non-target species, especially those that are filter-feeders. The Reserve's Research Program conducts periodic assessments of the softshell clam resource for the Town of Wells Clam Commission (Fig. 9-2, photo, Dalton and Dillon 2004).

Land Use Change

Marine and estuarine invertebrates generally occupy lower trophic levels, especially in nearshore habitats such as salt marshes and mudflats. The fact that many of the inverte-

A handful of young soft-shelled clams (Mya arenaria) with a few amethyst gem clams (Gemma gemma) from the northern reaches of the Webhannet Estuary, 2004. Photo Cayce Dalton.

brates are sessile and filter-feeders implies that they may be more susceptible to negative impacts associated with land use change. Examples of collateral damage due to reduced vegetative buffer or increased impervious surface include: increased sedimentation, changes in salinity and temperature regime due to increased freshwater input and increased nutrient and pollutant loads.

Harbor Dredging

Similar to land use change, dredging can cause increased sedimentation, which can inhibit the filter feeding of many invertebrate species. In addition, sessile species are susceptible to being buried by dredged material disposal.

Marine Traffic

High levels of boat traffic, especially if it is at high speeds in soft-sediment environments, can lead to high turbidity and sedimentation levels. Suspended particulates inhibit respiration in filter-feeders and may reduce feeding efficiency if the suspended materials are mostly inorganic or harmful if ingested (e.g. contaminated with heavy metals). Energy from wakes is often excessive and erodes salt marsh habitat.

Sea Level Rise and Climate Change

Many marine organisms are highly influenced by water temperature. Water temperature influences basal metabolic rates of ectothermic animals in addition to development times for larvae. Changes in sea surface temperatures have been implicated in range extensions and shifts in the distribution patterns of a variety of marine organisms from the Gulf of Maine and in other cold-temperate oceans. Increased frequency and severity of storms due to climate change will likely lead to increased physical stress for invertebrates due to changes in salinity regime, dislodgement and increased sedimentation associated with big storms.

RESEARCH ON MARINE AND ESTUARINE INVERTEBRATES

Although there has not been a concerted effort designed to document all the species of marine invertebrates at the Reserve, there have been a number of studies that provide a solid basis for describing and estimating the diversity of invertebrates in our vicinity. Table 9-1 provides a species list for all the known taxa that exist within the Reserve.

More and larger boats on small tidal rivers can lead to salt marsh bank erosion. Photo Michele Dionne.

Many of the studies described below have been focused on basic ecological interactions and therefore have been more quantitative rather than descriptive in nature.

Currently, Reserve graduate research fellows, Genevieve Bernatchez and Robert Vincent, are conducting two invertebrate-focused studies. Below is a description of Bernatchez's dissertation research, which is focused on the Asian Shore crab, *Hemigrapsus sanguineus*, in mudflat habitats:

Indirect Effects of Crabs in Mudflat Habitats

The importance of the direct effects of predatory invasive species like the Asian shore crab, *Hemigrapsus sanguineus*, and the green crab, *Carcinus maenas*, on community

The invasive Carcinus maenas. This crab was hosted in the Coastal Ecology Center. Photo Hannah Wilhelm.

structure is well known, but experimental studies often overlook the indirect effects of such predators (e.g. trophic cascades, trait-mediated indirect interaction, competition). We have a limited understanding of how these indirect interactions influence salt marsh community structure, particularly when invasive predators are involved. Bernatchez is exploring the effects of The Asian shore crab and the green crab on the common periwinkle, *Littorina littorea*, and its interactions with the benthic macroinfaunal mud flat community. Preliminary results indicate that green crab risk cues suppress snail-feeding rates to a degree that ultimately affects the abundance of several macroinfaunal species. Reduced grazing by the snails in response to the presence of crabs may lessen the competition between the snails and macroinfauna for food resources, allowing the macroinfaunal community to thrive. Certainly, the potential for trait-mediated indirect effects involving mobile predators, such as these invasive crabs, warrants further investigation.

Vincent's research is concerned with assessing the differences in habitat quality between natural pools and pools that were created by a wildlife management technique known as ditch-plugging. In 2006, he conducted a field experiment to test for differences in marsh fish production and predation on the benthic invertebrate community in natural pools and in ditch-plugged pools. A summary of his dissertation research follows.

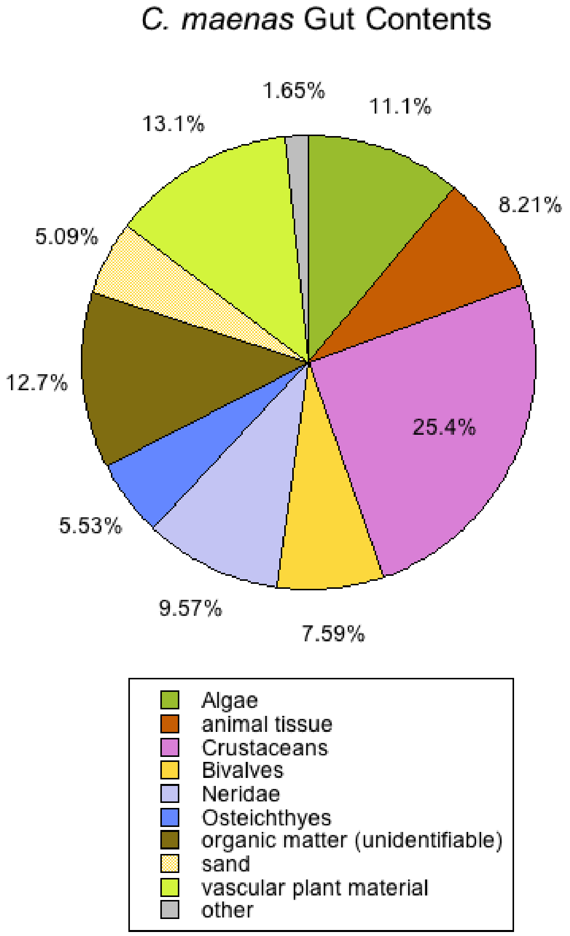


Figure 9-1: Mean percent composition of *C. maenas* gut contents. The perecentages are weighted to account for gut fullness. Data Edgerly (2006). Figure Hannah Wilhelm.

Impacts of Ditch Plugging on Marsh Fish Consumption of Benthic Invertebrates

The practice of ditch-plugging is currently being employed as a method for salt marsh habitat restoration and enhancement, but the long-term impacts from this technique are unclear. Additionally, human-made ditches have existed on salt marshes for decades, but the effects of ditching on ecological functions are only poorly understood. Clearly, a greater understanding of ecological changes due to hydrologic alterations is needed. The purpose of this study is to investigate ecological responses to anthropogenic alterations of salt marsh habitat and how these responses compare to the functions and ecological interactions observed in naturally occurring salt marsh systems. The objective is to improve understanding of the long-term effects of ditching and ditch plugging on hydrology and the resulting impacts to surrounding habitat and wildlife use. The study will compare the hydrologic regimes of human-made alterations (ditches and ditch-plug pools) with naturally occurring creeks and pools. This study will complement the findings of earlier studies by 1) investigating the effects of the initial alteration (mosquito ditching) and 2) comparing the influences that human-made ditches and ditch-plug pools versus natural creeks and pools have on the functions and values of channel/pool salt marsh habitat. This study will answer questions relating to hydrology, water quality, soil characteristics, vegetation communities, and wildlife use. It is anticipated that the study will also generate additional questions requiring further investigation that may aid in designing habitat restoration and enhancement methodologies that avoid unintended (and potentially negative) long-term impacts to salt marsh ecological functions.

Effects of the Green Crab on Benthic Invertebrates of the Vegetated Marsh

In 2005, Reserve staff conducted an experiment to assess the impact of predation by the green crab, *Carcinus maenas*, on the benthic community. The motivation for the study stemmed from the observation that green crabs constitute the highest biomass of any nektonic species on the vegetated marsh surface. Core samples for benthic invertebrates were taken before and after a caging experiment where green crabs were either enclosed or excluded on the vegetated marsh. The epifauna and infauna captured within the cores are currently being separated from the peat, counted and identified.

Edgerly (2006) used stomach contents and stable isotope analysis to investigate the diet and trophic position of *Carcinus maenas*. Crabs were collected from four locations along the nearby York River for gut content analysis. Gut contents (Fig. 9-1) describe the green crab as a opportunistic generalist predator, a result consistent with earlier studies. A controlled feeding experiment to determine the ratios of the stable isotopes ($\delta^{13}C$ and $\delta^{15}N$; see CH. 17 for more on stable isotopes) in *C. maenas* and its prey (*Fundulus heteroclitus*, *Mya arenaria*, and *Fucus spiralis*) suggested competition between *C. maenas* and native predators for food.

Effects of Grazing by the Common Perwinkle on Salt Marsh Cordgrass

In 2004 and 2005, Wells NERR staff conducted a manipulative experiment to assess whether grazing pressure by the common periwinkle, *Littorina littorea*, affected the abundance of salt marsh cordgrass, *Spartina alterniflora*. The experiment was conducted in the Webhannet and Little Rivers at the transition zone of low marsh to mudflat, where *L. littorea* occurs in very high densities. In the Webhannet River, snails caused a significant decline in biomass of *smooth cordgrass* indicating that their high densities may depress production of this plant with potentially myriad indirect effects.

Green Crabs and Soft-Shell Clams

Whitlow's (2002) dissertation research focused on quantifying the impacts of the introduced green crab, *Carcinus maenas*, on the soft-shell clam, *Mya arenaria*. He assessed clam survival in relation to their protection or exposure to crab predation as well as their morphological and behavioral changes relative to crab predation risk. In addition to their effects on the clams, green crabs also apparently had other indirect effects on mudflat-dwelling infaunal invertebrates. He found that the diversity and total abundance of seven benthic species that were protected from crab predation was higher than those plots that were exposed to crab predation. The seven species were: the amphipod, *Gammarus mucronatus*, juvenile green crabs, *Carcinus maenas*, fly larvae of the genus *Culicoides*, the polychaete, *Neanthes virens*, the common periwinkle, *Littorina littorea* and the clams *Macoma balthica* and *Mya arenaria*.

Figure 9-2: Map of softshell clam biomass in the Webhannet estuary (Dalton and Dillon 2004).

Secondary Production in Salt Marsh Pools

In 2002 and 2003, Wells NERR staff used stable isotopes and traditional growth assessments to examine the relative contribution of high marsh and marsh pool habitat to secondary production in mummichogs, *Fundulus heteroclitus*. Benthic invertebrates in the pools were sampled monthly in the Webhannet and Moody marshes using small grab samplers. Grass shrimp, *Palaemonetes pugio*, and green crabs were commonly encountered in the pools. Other species that were found include: *Gammarid amphipods* and *harpacticoid copepods* (MacKenzie and Dionne 2006).

Benthic Habitat Mapping in the York and Webhannet Rivers

In 2001, Wells NERR and NOAA Coastal Services Center researchers surveyed the benthic habitats of the York and Webhannet Rivers using a sediment profile image (SPI) camera and benthic grab samples. They found a total of 180 taxa for both river systems combined, and the diversity of the York River sites was higher than that of the Webhannet (Fig. 9-3). A thorough community analysis indicated that polychaetes and oligochaetes were the numerically most abundant groups in the shallow waters of the Webhannet. The abundance of invertebrates was inversely related to sediment grain size in the Webhannet. Bivalves, specifically, the blue mussel, *Mytilus edulis*, were concentrated at the mouth of Wells Harbor. For both the York and Webhannet rivers, the biomass of molluscs, which was dominated by *Mytilus*, comprised the highest fraction of total ash free dry weight. The report also documents the relationship between distinct community clusters and their relationship to various physical factors such as depth, sediment grain size and salinity (Diaz *et al.* 2005). Finally, maps depicting the relative abundance of major species and groups (e.g. gastropoda, bivalvia) in each of the river systems are provided in the report.

Factors Influencing Juvenile Soft-shell Clam Distribution

Millbury's (1997) undergraduate honors thesis investigated the relationship between juvenile *Mya arenaria* and adult clam density, sample location, substrate composition and sediment organic content. Juvenile clam response parameters assessed included density, length and width. Using a multiple regression, she found a positive relationship between clam density and distance from the inlet on the Webhannet River and sediment percent organic matter. None of the other parameters that were assessed significantly affected juvenile clam density or size.

Benthic Communities in the Webhannet River Estuary Prior to Dredging

In 1995 and 1996, the Wells Reserve staff collected benthic invertebrate samples as a precursor to a dredge monitoring study. Samples were collected from a variety of sites in the Webhannet River in anticipation that the community structure would be affected by dredging activities at some of these sites. Benthic infaunal and epifaunal species that were encountered in sediment cores include: polychaetes, (the clam worm, *Neanthes virens*, *Heteromastus filiformis*, and red-lined worms of the family Nephtyidae, orbiniid worms [e.g., *Scoloplos* sp.]), amphipods (*Corphium volutator*, and the digger amphipod, *Haustorius canadensis*), nemerteans (e.g. the ribbon worm, *Cerebratulus luridus*), nematomorphs, (e.g. horse hair worm, *Nectonema agile*), oligochaetes (e.g. *Enchytraeus albidus*) and molluscs (*Mya arenaria*, *Macoma balthica*, *Gemma gemma*, *Mytilus edulis* and *Modiolus modiolus*). They also encountered American Sand Lance, *Ammodytes americanus*, while taking the samples.

Distribution and Abundance of Mya Arenaria and Other Macroinfauna in the Little River and Webhannet River Estuaries

In 1994, Wells Reserve staff conducted benthic sampling in the Little and Webhannet Rivers as part of an ecological characterization as required for all National Estuarine Research Reserves. They dug quadrats to obtain clam densities and took core samples to obtain densities of other macroinfauna. They also assessed *Mya*'s survival and growth at varying densities and protection from predation. For macroinfauna, they found higher species richness in the Webhannet River, with 18 macroinfaunal species recovered versus only 11 species from the Little River. They attributed the higher species richness in the Webhannet River to the sediment grain size and associated physical factors such as salinity and current speed. The major groups they encountered were bivalves, amphipods and annelids. The soft-shell clam had greater densities and growth rates in the Little River than in the Webhannet River.

Meiofauna Species Composition of the Little and Webhannet River Estuaries

From 1992 to 1993, Reserve staff, in conjunction with university researchers, conducted monthly or bi-

A pair of juvenile polychaete sandworms (Genus: Neanthes). Photo Jeremy Miller.

monthly sampling for ichthyoplankton, zooplankton and meiofauna. Meiofauna were sampled in the Little and Webhannet Rivers. The meiofauna data were not summarized, but 12 major groups were found including Turbellarians, Gastrotrichs, Rotifers, Cladocerans, Ostracods and Copepods, in addition to other more familiar groups such as polychaetes (pictured).

RESEARCH NEEDS

Role of Introduced Species in Modifying Productivity, Community Structure

As previously mentioned, there are several extremely abundant introduced species in the estuarine habitats at the Reserve. Despite their high densities and biomass, there has been little research aimed at assessing the impacts of these introduced species on primary or secondary productivity of the marsh system. In addition to diversion of energy, the introduced species likely affect native organisms through altered habitat utilization, reduced foraging efficiency, or other trait-mediated interactions. Several projects currently under way at the Reserve focus on assessing the effects of introduced crabs on the benthic prey community, and another project focuses on the impact of grazing by the common periwinkle. A neglected aspect of the ecology of introduced species is the interactions of these introduced species with higher trophic levels (e.g. birds, larger fish and crustaceans). In order to fully assess how introduced species affect energy flow in estuarine food webs, future research should address higher trophic levels, parasite transmission and other effects of introduced species other than their dietary habits and effects on potential competitors.

Effects of Tidal Restrictions on Marsh and Mudflat Community Structure

Tidal restrictions reduce the volume and duration of flooding on marsh surfaces. Although there is very little information regarding the impacts of tidal restrictions on benthic invertebrates, it is likely that this group of organisms is particularly strongly affected by alterations of the natural flooding regime. For example, upstream from a tidal restriction the species composition is likely shifted in favor of fresh-water organisms relative to euryhaline

Aerial photo of impounded water behind Drakes Island Road, in the northern Webhannet Estuary, due to tidal restriction at the road. A self-regulating tide gate has since been installed. Photo Wells NERR.

or stenohaline species. In addition, the reduced tidal flushing likely leads to sedimentation and reduced flux of planktonic food for benthic filter feeders. Increased research efforts should be directed at documenting and mitigating the impacts of tidal restrictions on sessile invertebrates, especially those species that have prominent ecological functions such as promoting nutrient cycling and transferring energy from the water column to the benthos.

Support Research on Poorly Characterized Groups (e.g. Meiofauna)

As described above, there is very little information about the species composition and abundance of some of the smaller invertebrate groups at the Reserve. Some members of poorly characterized groups could be important ecological indicators (e.g. parasites) and thus efforts should be made to support research on these smaller, less conspicuous invertebrate species.

MANAGEMENT RECOMMENDATIONS

Support Monitoring of Dominant, Characteristic, Indicator and Invasive Species

Aside from short-term, hypothesis-oriented research conducted by students, staff and visiting researchers, we have virtually no information about how populations of important invertebrate species may be changing at the Wells NERR. This lack of information hinders our ability to forecast or even detect major shifts in the distribution or abundance of important invertebrate species. The Asian shore crab, *Hemigrapsus sanguineus*, is increasing its distribution and abundance in the Gulf of Maine although it is not yet common in soft-sediment habitats. If this crab becomes abundant at the Wells NERR, populations of *Mya arenaria* and other bivalves may decline even further than they did when *Carcinus maenas* invaded. Invertebrate surveys could be focused on a select group of conspicuous species such as *Carcinus*, *Mya*, *Gemma gemma*, *Mercenaria mercenaria*, *Littorina littorea*, *Littorina saxatilis*, *Illynassa obseleta*, etc. Volunteers could easily be trained to distinguish these species and they could conduct rapid population assessments every three years to document fluctuations in their abundance. This type of survey would also aid in the detection of new species invasions.

Reduce Impact of Tidal Restrictions

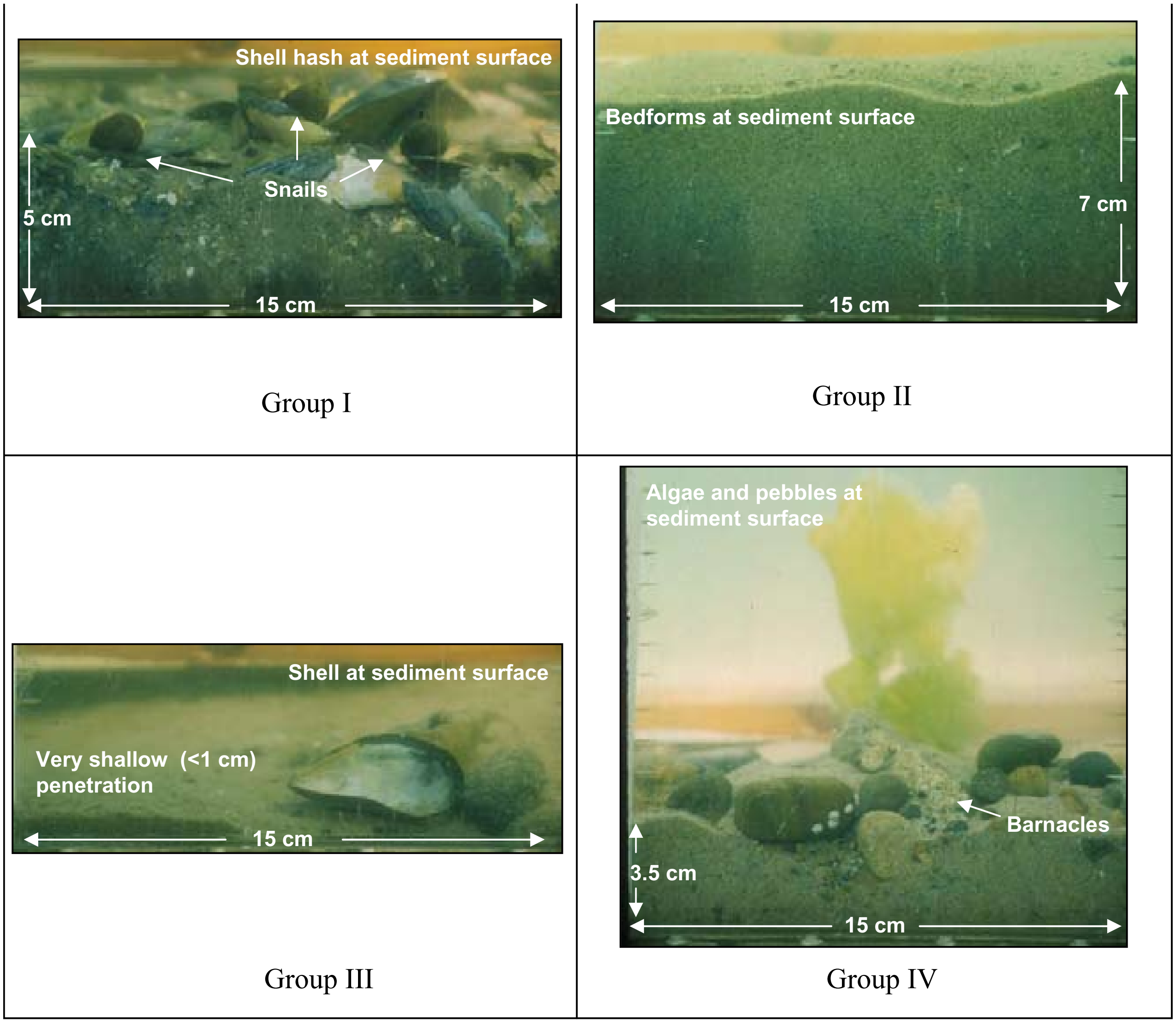
One step that is being taken to improve the status of marine and estuarine invertebrates at the Wells NERR is the restoration of tidal exchange under the Drakes Island Road. Increasing tidal flow to the north half of Drakes Island marsh (the eastern terminus of the Webhannet River) would allow marsh plants and invertebrates to re-colonize this area. In addition to the benefits derived from restoring the marsh community (see Ch. 7 for more on the functions and values of salt marshes), the abundance of commercially important species such as *Mya arenaria* and *Neanthes virens* would likely increase.

Reduce Pollution and Runoff

Upland land use affects the quality of estuarine habitats by increasing the rate and amount of freshwater runoff, pollutants and nutrient loading. Intact forest and freshwater wetland communities mitigate negative impacts of upland land use on estuarine communities. Educating coastal property owners in the Little and Webhannet watersheds about the impacts of their land use decisions on natural communities will help them make ecologically responsible decisions. The Wells NERR can lead by example by maintaining a minimum of a 100-ft vegetated buffer on all land that borders tidally influenced streams and installing interpretative signs explaining the vegetated buffer concept.

Examine Possible No-take Zones

Recreational and commercial clamming and worm digging disturbs large portions of the mudflats in the Webhannet River. Although compared to other fishing practices this type of harvesting may seem to be relatively low impact, but many non-target species are uprooted, crushed or buried as a consequence of digging. The es-



Group I

Group II

Group III

Group IV

Figure 9-3: Sediment Profile Images showing benthic features from the Webhannet River. Representative images from each benthic community identified through cluster analysis. Photos Wells NERR.

tablishment of some no-take zones might be considered in the Webhannet River to protect a portion of the habitat from this type of anthropogenic disturbance. These protected sections will provide a valuable reference for researchers to assess the indirect effects of clamming and worm digging. In addition, a growing body of research shows that fishery yields are enhanced when at least a small fraction of the habitat is protected from harvesting (e.g. Palumbi 2001, Lubchenco *et al.* 2003).

REFERENCES

Behrens Yamada, S. and R.A. Mansour. 1987. Growth inhibition of native *Littorina saxatilis* (Olivi) by introduced *L. littorea* (L.). Journal of Experimental Marine Biology and Ecology. 105(2-3): 187-196.

Brenchley, G.A. and J.T. Carlton. 1983. Competitive displacement of native mud snails by introduced periwinkles in the New England intertidal zone. Biological Bulletin 165: 543-558.

Commito, J.A. and P.B. Shrader. 1985. Benthic community response to experimental additions of the polychaete *Nereis virens*. Marine Biology 86(1): 101-107.

Diaz, R.J., R. Rowe, P. Wilbur, K. Schaefer, M. Dionne, R.A. McKenzie. 2005. Benthic habitat mapping project: Webhannet and York River estuaries, Wells National Estuarine Research Reserve, Maine. Final Report. NOAA/CSC/20517-PUB to National Oceanic and Atmospheric Administration Coastal Services Center, Charleston, SC. 68 pp.

Edgerly, J. 2006. Trophic role of the invasive crab Carcinus maenas in a Southern Maine marsh described by stable isotopes and gut contents. Undergraduate senior thesis, Bates College, Lewiston, ME. 50 pp.

Lubchenco, J., S.R. Palumbi, S.D. Gaines and S. Andelman. 2003. Plugging a hole in the ocean the emerging science of marine reserves. Ecological Applications 13(1): S3-S7.

MacKenzie, R.A. and M.D. Dionne. 2006. Ecological processes, energy pathways, and the impact of human activities on Maine marsh-estuarine secondary production: a salt marsh panne model. Report to be submitted to Maine Sea Grant, NOAA grant NA16RG1034, R-02-06. 54 pp.

Millbury, C.A. 1997. The distribution of the soft-shell clam *Mya arenaria* (Linnaeus) recruits within the Webhannet estuary, Wells, Maine. Senior Honors Thesis. University of New Hampshire. 39 pp.

Palumbi, S.R. The ecology of marine protected areas. *In* Marine community ecology. *Edited by* M.D. Bertness, S.D. Gaines and M.E. Hay. Sinauer Assoc., Sunderland, MA. pp. 509-530.

Pennings, S. C., M.D. Bertness. Salt marsh communities. 2001. *In* Marine community ecology. *Edited by* M.D. Bertness, S.D. Gaines and M.E. Hay. Sinauer Assoc., Sunderland, MA. pp. 289-316.

Tyrrell, M.C. and J.E. Byers. Do artificial substrates favor non-indigenous fouling species over natives? Journal of Experimental Marine Biology and Ecology. In press.

Whitlow, W.L. 2002. Changes in native species after biological invasion: effects of introduced green crabs on native soft-shell clams and an estuarine community. Dissertation in Ecology and Evolutionary Biology. University of Michigan, Ann Arbor, MI. 310 pp.

Table 9-1: All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
Annelida	Clitellata	Haplotaxida	Naididae	*Paranais litoralis*	
			Tubificidae	Tubificidae sp.	
				Hirudinea sp.	
	Polychaeta	Aciculata	Dorvilleidae	*Parougia caeca*	
				Ougia sp.	
			Eunicidae	*Eunice pennata*	
			Goniadidae	*Goniada maculata*	
			Hesionidae	*Microphthalmus pettiboneae*	
				Podarke obscura	
			Lumbrineridae	*Lumbrineris acicularum*	
				Lumbrineris fragilis	
				Lumbrineris tenuis	
				Ninoe nigripes	
			Nephtyidae	*Aglaophamus neotenus*	
				Nephtys bucera	
				Nephtys caeca	
				Nephthys incisa	
			Nereididae	*Neanthes succinea*	
				Neanthes virens	
				Nereis diversicolor	
				Nereis pelagica	
				Nereis zonata	
			Oenonidae	*Arabella iricolor*	
				Drilonereis longa	
			Pholoidae	*Pholoe tecta*	
			Phyllodocidae	*Anaitides groenlandica*	
				Anaitides maculata	
				Anaitides mucosa	
				Eteone longa	
				Paranaitis speciosa	
				Phyllodoce sp.	
			Polynoidae	*Arcteobia anticostiensis*	
				Bylgides sarsi	
				Gattyana cirrosa	
				Harmothoe extenuata	
				Harmothoe imbricata	
				Lepidonotus squamatus	
			Sigalionidae	*Sthenelais limicola*	
			Syllidae	Autolytinae sp.	
				Autolytus cornutus	
				Exogone hebes	
				Sphaerosyllis sp.	
				Streptosyllis varians	
		Canalipalpata	Ampharetidae	*Ampharete acutifrons*	
				Asabellides oculata	
				Melinna cristata	
			Apistobranchidae	*Apistobranchus tullbergi*	
			Cirratulidae	*Cirratulus grandis*	
				Tharyx acutus	
			Flabelligeridae	*Flabelligera affinis*	
				Pherusa affinis	
			Oweniidae	*Galathowenia oculata*	
			Pectinariidae	*Cistenides granulata*	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
				Pectinaria granulata	
			Polygordiidae	*Polygordius* sp.	
			Sabellidae	*Euchone rubrocincta*	
				Fabricia sabella	
				Potamilla neglecta	
			Serpulidae	*Dexiospira spirillum*	
				Spirobis borealis	
			Spionidae	*Marenzelleria viridis*	
				Polydora caulleryi	
				Polydora cornuta	
				Polydora quadrilobata	
				Polydora socialis	
				Polydora websteri	
				Prionospio steenstrupi	
				Pygospio elegans	
				Scolelepis squamata	
				Scolelepis texana	
				Spio filicornis	
				Spio setosa	
				Spio thulini	
				Spiophanes bombyx	
				Streblospio benedicti	
			Sternaspidae	*Sternapsis scutata*	
			Terebellidae	*Nicolea zostericola*	
			Arenicolidae	*Arenicola marina*	
			Capitellidae	*Capitella capitata*	
				Heteromastus filiformis	
				Mediomastus ambiseta	
			Cossuridae	*Cossura longocirrata*	
			Maldanidae	*Clymenella torquata*	
				Euclymene zonalis	
				Macroclymene zonalis	
				Maldane sarsi	
				Praxillella gracilis	
				Praxillella praetermissa	
			Opheliidae	*Ophelina acuminata*	
			Orbiniidae	*Leitoscoloplos fragilis*	
				Naineris quadricuspida	
				Orbinia ornata	
				Scoloplos acutus	
				Scoloplos armiger	
				Scoloplos robustus	
			Paraonidae	*Acmira catherinae*	
				Aricidea quadrilobata	
				Aricidea suecica	
				Levinsenia gracilis	
				Paradoneis armata	
				Paraonis fulgens	
			Scalibregmatidae	*Scalibregma inflatum*	
Arthropoda	Arachnida			*Acarina* spp.	
		Opiliones	Phalangodidae	*Phalangodidae* spp.	Daddy Longlegs
		Parasitiformes	Ixodidae	*Ixodidae scapularis*	Deer Tick
		Araneae (Spiders)	Araneidae	*Argiope* sp.	Goldenrod Spider

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
			Theridiidae	*Enoplognathat ovata*	
			Linyphiidae	*Linyphia triangularis*	
				Hypselistes florens	
			Tetragnathidae	*Tetragnatha laboriosa*	
				Tetragnatha sp.	
			Araneidae	*Araneidae* sp.	
				Araneus pratensis	
				Mangora gibberosa	
				Mangora sp.	
				Neoscona arabesca	
				Neoscona sp.	
			Lycosidae	*Pardosa distincta*	
				Hogna sp.	
			Gnaphosidae	*Callilepis pluto*	
				Callilepis sp.	
				Micaria sp.	
			Philodromidae	*Tibellus oblongus*	
				Tibellus maritimus	
			Thomisidae	*Misumena vatia*	
				Misumenoides sp.	
				Xysticus huctans	
				Xysticus triguttatus	
				Xysticus sp.	
			Salticidae	*Eris* sp.	
				Evarcha hoyi	
				Habronattus borealis	
				Habronattus viridipes	
				Pelegrina galathea	
				Pelegrina proterva	
				Phidippus clarus	
				Phidippus princeps	
				Salticidae sp.	
	Branchiopoda	Diplostraca	Podonidae	*Podon leuckartii*	
				Evadne sp.	
	Cladocera			Cladocera sp.	
	Entognatha	Collembola		Collembola spp.	Water Fleas
			Hypogastruridae	*Anurida maritima*	Springtails
			Poduridae	*Achorutes* spp.	Snow Fleas
	Insecta	Coleoptera (Beetles)	Tenebrionidae	*Hypogastrura nivicola*	Comb-Clawed Beetle
			Carabidae	*Capnochroa fuliginosa*	Ground Beetle
			Carabidae	*Agonum gratiosum*	Ground Beetle
			Carabidae	*Calosoma* sp.	Ground Beetle
			Carabidae	*Anisodactylus harrisi*	Saltmarsh Tiger Beetle
			Chrysomelidae	*Cicindela marginata*	Leaf Beetle
			Coccinellinae	*Galerucella* sp.	Salt Marsh Lady Beetles
			Hydrophiloidea	*Naemia seriata*	Water Scavenger Beetle
			Meloidae	*Meloe* sp.	Blister Beetle
		Dictyoptera	Mantidae	*Mantis religiosa*	Praying Mantis
		Diptera	Canacidae	Canacidae sp.	
			Ceratopogonidae	*Bezzia* sp.	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
				Culicoides sp.	
			Chironomidae	*Chironomus* sp.	
				Dicrotendipes sp.	
				Goeldichironomus devineyae	
			Dolichopodidae	Dolichopodidae sp.	
			Tachinidae	*Proopia* sp.	Beetle Mite
			Tabanidae	*Chrysops* sp.	Deer Fly
			Simuliidae		Black Flies
			Stratiomyidae		Soldier Flies
			Tabanidae	*Tabanus* sp.	Greenhead Fly
			Culicidae (Mosquitos)	*Aedes abserratus*	
				Aedes atropalpus	
				Aedes canadensis	
				Aedes cantator	
				Aedes cinereus	
				Aedes diantaeus	
				Aedes communis	
				Aedes communis	
				Aedes excrucians	
				Aedes fitchii	
				Aedes intrudens	
				Aedes japonicus	
				Aedes provocans	
				Aedes punctor	
				Aedes sollicitans	
				Aedes sticticus	
				Aedes stimulans	
				Aedes triseriatus	
				Aedes trivittatus	
				Aedes vexans	
				Anopheles punctipennis	
				Anopheles quadrimaculatis	
				Anopheles walkeri	
				Coquillettidia perturbans	
				Culex pipiens	
				Culex restuans	
				Culex restuans / pipiens complex	
				Culex salinarius	
				Culex territans	
				Culiseta melanura	
				Culiseta minnesotae	
				Culiseta morsitans	
				Psorophora ferox	
				Uranotaenia sapphirina	
				Aedes taeniorhynchus	
		Ephemeroptera (Mayflies)	Ephemerida	Ephemerida spp.	Mayfly
		Hemiptera (True bugs)	Saldidae	Saldidae spp.	Shorebugs
			Gerridae	*Gerris* sp.	Water Strider
			Corixidae	*Trichocorixa verticalis*	Water Boatman
				Corixidae spp.	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
			Hydrometridae	Hydrometridae spp.	Marsh Treader
			Cercopidae	*Philaenus spumarius*	Spittlebugs
			Delphacidae	Delphacidae sp.	
			Psocoptera	Pscopotera sp.	
		Hymenoptera (Ants, Bees, and Wasps)	Argidae	*Arge* sp.	Argid Sawfly
			Tiphiidae		Parasitic Tiphiid Wasp
			Apidae	*Bombus pennsylvanicus*	Bumblebee
			Cynipidae	*Rhodites rosae*	Cynipid Wasp
			Pelecinidae	*Pelecinus polyturator*	Plecinid Wasp
		Lepidoptera	Arctiidae (Tiger Moths and Lichen Moths)	*Estigmene acrea*	Acrea Moth / Salt Marsh Moth
				Ctenucha virginica	Virginia Ctenucha
				Pyrrharctia isabella	Isabella Tiger Moth / Banded Woolybear
				Hyphantria cunea	Fall Webworm Moth
			Geometridae (Geometrid Moths)	sp.	Geometer Moth
			Lycaenidae (Gossamer-wing Butterflies)	*Lycaenea phlaeas*	American Copper Butterfly
				Celastrina ladon	Common Blue Butterfly / Spring Azure
			Noctuidae (Owlet Moths)	*Acronicta Americana*	American Dagger Moth
			Nymphalidae (Brush-footed Butterflies)	*Vanessa atalanta*	Red Admiral
				Phyciodes cocyta	Northern Crescent
				Speyeria cybele	Great Spangled Fritillary
				Junonia coenia	Buckeye Moth
				Danaus plexippus	Monarch Butterfly
				Nymphalis antiopa	Mourning Cloak Butterfly
				Limenitis arthemis	Red Spotted Purple / White Admiral
				Cercyonis pegala	Common Wood Nymph
			Papilionidae (Parnassians and Swallowtails)	*Papilio canadensis*	Canadian Swallowtail
				Papilio polyxenes	Common Eastern Swallowtail
				Papilio magna	Eastern Tiger Swallowtail
				Papilio Troilus	Spicebush Swallowtail
			Pieridae (Whites and Sulphurs)	sp.	White Butterflies
				Colias philodice	Clouded Sulphur
				Colias philodice	Common Sulphur Butterfly
				Colias euytheme	Orange Sulphur Butterfly

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
			Saturniidae (Wild Silk Moths)	*Hemileuca maia*	Buck Moth
				Callosamia promethean	Promethea Moth
				Dryocampa rubicunda	Rosy Maple Moth
			Lasiocampidae (Tent Caterpillar Moths)	*Malacosoma americanum*	Eastern Tent Caterpillar Moth
		Odonata	Calopterygidae (Broad-winged Damselflies)	*Calopteryx maculata*	Ebony Jewelwing
				Calopteryx aequabilis	River Jewelwing
				Hetaerina americana	American Rubyspot
			Lestidae (Spreadwings)	*Lestes d. disjunctus*	Common Spreadwing
				Lestes d. australis	Southern Spreadwing
				Lestes dryas	Emerald Spreadwing
				Lestes rectangularis	Slender Spreadwing
				Lestes vigilax	Swamp Spreadwing
				Lestes congener	Spotted Spreadwing
				Lestes eurinus	Amber-winged Spreadwing
				Lestes forcipatus	Sweetflag Spreadwing
				Lestes inaequalis	Elegant Spreadwing
				Lestes unguiculatus	Lyre-tipped Spreadwing
			Coenagrionidae (Pond Damselflies)	*Chromagrion conditum*	Aurora Damsel
				Enallagma aspersum	Azure Bluet
				Enallagma civile	Familiar Bluet
				Enallagma ebrium	Marsh Bluet
				Enallagma c. cyathigerum	Northern Bluet
				Enallagma signatum	Orange Bluet
				Enallagma geminatum	Skimming Bluet
				Enallagma exsulans	Stream Bluet
				Enallagma vesperum	Vesper Bluet
				Enallagma boreale	Boreal Bluet
				Enallagma divagans	Turquoise Bluet
				Enallagma hageni	Hagen's Bluet
				Enallagma laterale	New England Bluet
				Enallagma minusculum	Little Bluet
				Enallagma pictum	Scarlet Bluet
				Enallagma recurvatum	Pine Barrens Bluet
				Argia moesta	Powdered Dancer
				Argia f. violacea	Variable Dancer
				Ischnura hastata	Citrine Forktail
				Ischnura verticalis	Eastern Forktail
				Ischnura posita	Fragile Forktail
				Ischnura kellicotti	Lilypad Forktail

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
				Amphiagrion saucium	Eastern Red Damsel
				Nehalennia irene	Sedge Sprite
				Nehalennia gracilis	Sphagnum Sprite
			Aaeshnidae (Darners)	*Gomphaeschna furcillata*	Harlequin Darner
				Anax junius	Common Green Darner
				Boyeria vinosa	Fawn Darner
				Boyeria grafiana	Ocellated Darner
				Aeshna canadensis	Canada Darner
				Aeshna u. umbrosa	Shadow Darner
				Aeshna clepsydra	Mottled Darner
				Aeshna eremita	Lake Darner
				Aeshna tuberculifera	Black-tipped Darner
				Aeshna verticalis	Green-striped Darner
				Basiaeschna janata	Springtime Darner
				Nasiaeschna pentacantha	Cyrano Darner
				Epiaeschna heros	Swamp Darner
			Gomphidae (Clubtails)	*Stylogomphus albistylus*	Least Clubtail
				Gomphus exilis	Lancet Clubtail
				Gomphus spicatus	Dusky Clubtail
				Gomphus vastus	Cobra Clubtail
				Arigomphus villosipes	Unicorn Clubtail
				Arigomphus furcifer	Lilypad Clubtail
				Progomphus obscurus	Common Sanddragon
				Dromogomphus spinosus	Black-shouldered Spinyleg
				Hagenius brevistylus	Dragonhunter
				Ophiogomphus aspersus	Brook Snaketail
				Ophiogomphus howei	Pygmy Snaketail
				Ophiogomphus mainensis	Maine Snaketail
				Stylurus scudderi	Zebra Clubtail
			Cordulegastridae (Spiketails)	*Cordulegaster diastatops*	Delta-spotted Spiketail
			Macromiidae (Cruisers)	*Didymops transversa*	Stream Cruiser
				Macromia illinoiensis	Illinois River Cruiser
			Corduliidae (Emeralds)	*Dorocordulia lepida*	Petite Emerald
				Dorocordulia libera	Racket-tailed Emerald
				Somatochlora elongata	Ski-tailed Emerals
				Somatochlora incurvata	Incurvate Emerald
				Somatochlora kennedyi	Kennedy's Emerald
				Somatochlora walshii	Brush-tipped Emerald
				Cordulia shurtleffi	Amercian Emerald
				Epitheca canis	Beaverpond Baskettail

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
				Epitheca cynosura	Common Baskettail
				Epitheca princeps	Prince Baskettail
				Epitheca semiaquea	Mantled Baskettail
				Epitheca spinigera	Spiny Baskettail
				Neurocordulia obsoleta	Umber Shadowdragon
				Neurocordulia yamaskanensis	Stygian Shadowdragon
				Williamsonia fletcheri	Ebony Boghaunter
				Williamsonia lintneri	Ringed Boghaunter
				Helocordulia uhleri	Uhler's Sundragon
				Ladona exusta	White Corporal
			Libellulidae (Skimmers)	*Tramea carolina*	Carolina Saddlebags
				Tramea lacerata	Black Saddlebags
				Pantala flavescens	Wandering Glider
				Pantala hymenaea	Spot-winged Glider
				Perithemis tenera	Eastern Amberwing
				Celithemis elisa	Calico Pennant
				Celithemis eponina	Halloween Pennant
				Celithemis martha	Martha's Pennant
				Libellula cyanea	Spangled Skimmer
				Libellula incesta	Slaty Skimmer
				Libellula julia	Chalk-fronted Corporal
				Libellula luctuosa	Widow Skimmer
				Libellula needhami	Needham's Skimmer
				Libellula pulchella	Twelve-spotted Skimmer
				Libellula quadrimaculata	Four-spotted Skimmer
				Libellula semifasciata	Painted Skimmer
				Pachydiplax longipennis	Blue Dasher
				Erythemis simplicicollis	Eastern Pondhawk
				Erythrodiplax berenice	Seaside Dragonlet
				Nannothemis bella	Elfin Skimmer
				Leucorrhinia frigida	Frosted Whiteface
				Leucorrhinia glacialis	Crimson-ringed Whtiteface
				Leucorrhinia hudsonica	Hudsonian Whiteface
				Leucorrhinia intacta	Dot-tailed Whiteface
				Leucorrhinia proxima	Red-waisted Whiteface
				Sympetrum semicinctum	Band-winged Meadowhawk
				Sympetrum internum	Cherry-faced Meadwohawk
				Sympetrum janeae	Jane's Meadowhawk

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
				Sympetrum costiferum	Saffron-winged Meadowhawk
				Sympetrum obtrusum	White-faced Meadowhawk
				Sympetrum vicinum	Yellow-legged Meadowhawk
				Sympetrum rubicundulum	Ruby Meadowhawk
				Plathemis lydia	Common Whitetail
		Orhoptera	Rhaphidophoridae	*Ceuthophilus* sp.	Camel Cricket
			Gryllidae	Gryllidae spp.	Crickets
			Tettigoniidae	*Pterophylla camellifolia*	True Katydid
		Psocoptera		*Psocoptera* sp.	
		Trichoptera	Limnephilidae	Limnephilidae spp.	Northern Caddisflies
	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca abdita*	
				Ampelisca agassizi	
				Ampelisca vadorum	
			Ampithoidae	*Ampithoe rubricata*	
			Aoridae	*Microdeutopus gryllotalpa*	
				Unciola irrorata	
			Bateidae	*Batea catharinensis*	
			Calliopiidae	*Aeginina longicornis*	
				Calliopius laeviusculus	
			Caprellidae	*Caprella linearis*	
				Caprella penantis	
				Caprella penantis	
			Corophiidae	*Corophium volutator*	
				Monocorophium insidiosum	
			Dexaminidae	*Dexamine thea*	
			Eusiridae	*Pontogeneia inermis*	
			Gammaridae	*Gammarus lawrencianus*	
				Gammarus mucronatus	
			Haustoriidae	*Acanthohaustorius millsi*	
				Haustorius canadensis	
				Protohaustorius deichmannae	
			Hyalidae	*Hyale* sp.	
			Hyperiidae	*Themisto compressa*	
			Ischyroceridae	*Ischyrocerus anguipes*	
				Jassa marmorata	
			Lysianassidae	*Orchomenella* sp.	
				Psammonyx nobilis	
			Melitidae	*Melitidae* sp.	
			Pariambidae	*Paracaprella tenuis*	
			Phoxocephalidae	*Harpina* sp.	
				Phoxocephalus holbolli	
				Rhepoxynius epistomus	
				Trichophoxus sp	
			Pontoporeiidae	*Bathyporeia quoddyensis*	
			Protellidae	*Mayerella limicola*	
			Stenothoidae	*Proboloides holmesi*	
				Stenula peltata	
			Talitridae	*Orchestia gammarella*	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
		Cumacea	Uristidae	*Anonyx lilljeborgi*	
			Bodotriidae	*Cyclaspis* sp.	
				Iphinoe trispinosa	
				Mancocuma stelliferum	
				Pseudoleptocuma minus	
			Diastylidae	*Diastylis* sp.	
				Oxyurostylis smithi	
			Leuconidae	*Leucon americanus*	
			Nannastacidae	*Campylaspis rubicunda*	
		Decapoda	Cancridae	*Cancer irroratus*	
			Crangonidae	*Crangon septemspinosa*	
			Paguridae	*Pagurus* sp.	
			Palaemonidae	*Palaemonetes pugio*	
			Pandalidae	*Pandalus montagui*	
			Panopeidae	*Dyspanopeus texanus*	
			Portunidae	*Carcinus maenas*	
		Euphausiacea	Euphausiidae	*Thysanoessa gregaria*	
				Nyctiphanes couchii	
		Isopoda	Chaetiliidae	*Chiridotea* sp.	
			Idoteidae	*Edotia triloba*	
				Flabellifera sp.	
				Idotea balthica	
				Idotea phosphorea	
				Synisoma acuminatum	
				Valvifera sp.	
			Janiridae	*Jaera marina*	
		Mysida	Mysidae	*Heteromysis formosa*	Sow Bug
				Neomysis americana	
				Praunus flexuosus	
			Leptocheliidae	*Siriella armata*	
		Tanaidacea		*Hargeria rapax*	
		Tanaidacea		*Heterotanais groenlandicus*	
			Nototanaidae	*Tanaissus psammophilus*	
	Maxillopoda	Calanoida	Acartiidae	*Acartia clausi*	
			Calanidae	*Calanus finmarchicus*	
			Centropagidae	*Centropages typicus*	
			Clausocalanidae	*Pseudocalanus* sp.	
			Euchaetidae	*Paraeuchaeta norvegica*	
			Temoridae	*Temora longicornis*	
				Eurytemora sp.	
		Cyclopoida	Oithonidae	*Oithona* sp.	
			Cyclopidae	*Cyclops* sp.	Cyclops
		Harpacticoida	Copepoda	Copepoda spp.	Copepods
		Harpacticoida	Ectinosomatidae	*Microsetella* sp.	
		Harpacticoida	Harpacticidae	*Zaus* sp.	
		Harpacticoida		*Tigriopus* sp.	
		Sessilia	Thalestridae	*Parathalestris croni*	
		Sessilia	Archaeobalanidae	*Semibalanus balanoides*	
		Siphonostomatoida	Balanidae	*Balanus sp*	
		Siphonostomatoida	Caligidae	*Caligus* sp.	
	Mystacocarida			Mystacocarida sp.	
	Ostracoda			Ostracoda sp.	
	Pycnogonida	Pantopoda		*Anoplodactylus lentus*	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
			Phoxichilidiidae	*Phoxichilidium femoratum*	
Chaetognatha	Sagittoidea	Aphragmophora		*Parasagitta setosa*	
Chordata	Appendicularia	Copelata	Sagittidae	Sagittidae sp.	
		Copelata	Fritillaridae	*Fritillaria borealis*	
			Oikopleuridae	Oikopleuridae sp.	
	Ascidiacea			Ascidiacea sp.	
Cnidaria	Anthozoa	Actiniaria		Actiniaria sp.	
		Ceriantharia		Ceriantharia sp.	
	Hydrozoa	Hydroida	Campanulariidae	*Obelia* sp.	
			Corynidae	*Sarsia tubulosa*	
				Sarsia prolifera	
				Sarsia eximia	
			Laodiceidae	*Laodicea undulata*	
			Melicertidae	*Melicertum octocostatum*	
			Olindiidae	*Gonionemus* sp.	
			Tubulariidae	*Tubularia* sp.	
		Siphonophora		Siphonophora sp.	
		Trachylina	Rhopalonematidae	*Aglantha digitalis*	
	Scyphozoa	Semaeostomeae	Ulmaridae	*Aurelia* sp.	
Ctenophora				Ctenophora sp.	
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Asterias rubens*	
				Asterias forbesi	
		Spinulosida	Pterasteridae	Pterasteridae sp.	
	Echinoidea	Clypeasteroida	Echinarachniidae	*Echinarachnius parma*	
		Echinoida	Strongylocentrotidae	*Strongylocentrotus droebachiensis*	
	Holothuroidea	Dendrochirotida	Cucumariidae	*Cucumaria frondosa*	
	Ophiuroidea	Ophiurida	Amphiuridae	*Amphipholis squamata*	
			Ophiactidae	*Ophiopholis aculeata*	
			Ophiuridae	*Ophiura robusta*	
Ectoprocta	Gymnolaemata	Cheilostomata	Membraniporidae	*Membranipora membranacea*	
Ectoprocta	Gymnolaemata	Cheilostomata	Electridae	*Electra pilosa*	
Gastrotricha				Gastrotricha sp.	
Gnathostomulida			Gnathostomulida sp.		
Hemichordata	Enteropneusta			Enteropneusta sp.	
Kinorhyncha				Kinorhyncha sp.	
Mollusca	Aplacophora			Aplacophora sp.	
	Bivalvia	Arcoida	Arcidae	*Anadara transversa*	
	Bivalvia	Myoida	Hiatellidae	*Hiatella arctica*	
			Myidae	*Mya araenaria*	
		Mytiloida	Mytilidae	*Crenella* sp.	
				Modiolus modiolus	
				Mytilus edulis	
		Nuculoida	Nuculidae	*Nucula delphinodonta*	
				Nucula proxima	
		Nuculoida	Nuculanidae	*Nuculana* sp.	
			Yoldiidae	*Yoldia* sp.	
		Ostreoida	Anomiidae	*Anomia simplex*	
				Anomia squamula	
			Pectinidae	*Argopecten irradians*	
		Pholadomyoida	Lyonsiidae	*Lyonsia arenosa*	
			Thraciidae	*Thracia* sp.	
		Veneroida	Arcticidae	*Arctica islandica*	

Table 9-1 (continued): All invertebrates found within Wells NERR estuaries and uplands. MacKenzie 2004, Jennings 2001, Wells NERR 2005, 2006 (Benthic Habitat Mapping Project), York County Odonate Survey, MacKenzie and Dionne, Lubelczyk 2005, Morgan 2005.

Phlyum	Class	Order	Family	Species or Assembly of Species	Common Name
			Astartidae	*Astarte undata*	
			Cardiidae	*Cerastoderma pinnulatum*	
			Lasaeidae	*Aligena elevata*	
				Mysella planulata	
			Mactridae	*Spisula solidissima*	
			Pharidae	*Ensis directus*	
			Solenidae	*Solen viridis*	
			Tellinidae	*Macoma balthica*	
				Tellina agilis	
			Thyasiridae	*Thyasira flexuosa*	
			Veneridae	*Gemma gemma*	
				Pitar morrhuanus	
	Gastropoda	Archaeogastropoda	Trochidae	*Margarites helicinus*	
		Cephalaspidea	Diaphanidae	*Diaphana minuta*	
		Heterostropha	Pyramidellidae	*Odostomia* sp.	
	Gastropoda	Neogastropoda	Buccinidae	*Buccinum undatum*	
			Columbellidae	*Astyris lunata*	
			Muricidae	*Nucella lapillus*	
			Nassariidae	*Nassarius trivittatus (Ilyanassa trivittata)*	Threeline Mud Snail
				Nassarius obsoletus (Ilyanassa obsoleta)	Eastern Mud Snail
		Neoloricata	Ischnochitonidae	*Ischnochiton ruber*	
				Tonicella sp.	
		Neotaenioglossa	Calyptraeidae	*Crepidula convexa*	
				Crepidula fornicata	
				Crepidula plana	
			Hydrobiidae	*Hydrobia truncata*	
			Littorinidae	*Littorina littorea*	Common Periwinkle
				Littorina saxatilis	Rough Periwinkle
				Littorina obtusata	Smooth Periwinkle
			Naticidae	*Naticidae* sp.	
			Rissoidae	*Onoba aculeus*	
		Nudibranchia	Corambidae	*Doridella obscura*	
			Acmaeidae	*Notoacmea testudinalis*	
	Polyplacophora			Polyplacophora sp.	
Nemata				Nemata sp.	
Nemertea	Anopla	Heteronemertea	Lineidae	*Micrura* sp.	
Phoronida			Phoronidae	*Phoronis* sp.	
Platyhelminthes	Turbellaria			Turbellaria sp.	
Porifera				Porifera sp.	
Priapula				Priapula sp.	
Protozoa	Ciliatea	Oligotrichida	Tintinnidiidae	*Tintinnidium* sp.	
Protozoa	Granuloreticulosea	Foraminiferida		Foraminiferida sp.	
Protozoa	Labyrinthulea	Piroplasmida		*Acanthochiasma* sp.	
Rotifera	Eurotatoria	Ploima	Synchaetidae	*Synchaeta* sp.	
Sipuncula			Golfingiidae	*Phascolion strombi*	
Tardigrada	Eurotatoria	Ploima			

Table 9-2: Zooplankton found within Wells NERR estuaries (extracted from Table 9-1).

Phylum	Class	Order	Family	Species or Assembly of Species
Protozoa	Ciliatea	Oligotrichida	Tintinnidiidae	*Tintinnidium sp.*
	Granuloreticulosea	Foraminiferida		Foraminiferida sp.
				Acanthochiasma sp.
	Labyrinthulea	Piroplasmida		
Porifera				Porifera sp.
Cnidaria	Anthozoa	Actiniaria		Actiniaria sp.
	Hydrozoa	Hydroida	Campanulariidae	*Obelia sp.*
			Corynidae	*Sarsia tubulosa*
				Sarsia prolifera
				Sarsia eximia
			Laodiceidae	*Laodicea undulata*
			Melicertidae	*Melicertum octocostatum*
			Olindiidae	*Gonionemus sp.*
			Tubulariidae	*Tubularia sp.*
		Siphonophora		Siphonophora sp.
		Trachylina	Rhopalonematidae	*Aglantha digitalis*
	Scyphozoa	Semaeostomeae	Ulmaridae	*Aurelia sp.*
Ctenophora				Ctenophora sp.
Rotifera	Eurotatoria	Ploima	Synchaetidae	Synchaeta sp.
Annelida	Polychaeta	Aciculata	Nephtyidae	*Nephtys caeca*
				Nephthys incise
			Nereididae	Nereis sp.
			Phyllodocidae	Phyllodoce sp.
			Polynoidae	*Harmothoe imbricata*
			Syllidae	Syllidae sp.
		Canalipalpata	Pectinariidae	*Pectinaria sp.*
			Spionidae	*Polydora socialis*
				Polydora quadrilobata
Mollusca	Bivalvia	Myoida	Myidae	*Mya araenaria*
		Mytiloida	Mytilidae	*Mytilus edulis*
		Ostreoida	Anomiidae	*Anomia simplex*
	Gastropoda	Neotaenioglossa	Littorinidae	*Littorina littorea*
Arthropoda	Branchiopoda	Diplostraca	Podonidae	*Podon leuckartii*
				Evadne sp.
	Insecta	Diptera	Chironomidae	Chironomidae sp.
	Malacostraca	Amphipoda	Gammaridae	*Gammarus sp.*
			Hyperiidae	*Themisto compressa*
		Cumacea	Bodotriidae	*Pseudoleptocuma minus*
				Iphinoe trispinosa
			Nannastacidae	*Campylaspis rubicunda*
		Decapoda	Cancridae	*Cancer* spp.
			Crangonidae	*Crangon septemspinosa*
			Paguridae	*Pagurus sp.*
			Pandalidae	*Pandalus montagui*
			Panopeidae	*Dyspanopeus texanus*
			Portunidae	*Carcinus maenas*
		Euphausiacea	Euphausiidae	*Thysanoessa gregaria*
				Nyctiphanes couchii
		Isopoda	Idoteidae	*Idotea sp.*
				Synisoma acuminatum
		Mysida	Mysidae	*Neomysis americana*
				Siriella armata
	Maxillopoda	Calanoida	Acartiidae	*Acartia clausi*
			Calanidae	*Calanus finmarchicus*
			Centropagidae	*Centropages typicus*

Table 9-2 (continued): Zooplankton found within Wells NERR estuaries (extracted from Table 9-1).

Phylum	Class	Order	Family	Species or Assembly of Species
			Clausocalanidae	*Pseudocalanus sp.*
			Euchaetidae	*Paraeuchaeta norvegica*
			Temoridae	*Temora longicornis*
				Eurytemora sp.
		Cyclopoida	Oithonidae	*Oithona sp.*
		Harpacticoida	Ectinosomatidae	*Microsetella sp.*
			Harpacticidae	*Zaus sp.*
				Tigriopus sp.
			Thalestridae	*Parathalestris croni*
		Sessilia	Archaeobalanidae	*Semibalanus sp.*
			Balanidae	*Balanus sp*
		Siphonostomatoida	Caligidae	*Caligus sp.*
				Ostracoda sp.
	Ostracoda			
Ectoprocta	Gymnolaemata	Cheilostomata	Membraniporidae	*Membranipora membranacea*
			Electridae	*Electra pilosa*
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Asterias rubens*
				Asterias forbesi
	Echinoidea	Echinoida	Strongylocentrotidae	*Strongylocentrotus droebachiensis*
	Holothuroidea	Dendrochirotida	Cucumariidae	*Cucumaria frondosa*
	Ophiuroidea	Ophiurida	Amphiuridae	*Amphipholis squamata*
Chaetognatha	Sagittoidea	Aphragmophora	Sagittidae	*Parasagitta setosa*
Chordata	Appendicularia	Copelata	Fritillaridae	*Fritillaria borealis*
			Oikopleuridae	*Oikopleura sp.*

CHAPTER 10

Reptiles and Amphibians

ROBERT BALDWIN, LORI JOHNSON, DANIEL ZEH, TIMOTHY DEXTER AND LESLIE LATT

There are thirty-eight species of reptiles and amphibians in Maine. By far the greatest diversity occurs in the southern third of the State, where several species reach their northeasternmost range limits (Hunter *et al*. 1999). Contributing to this reptile and amphibian diversity, southern coastal Maine has a diversity of plant communities and prevalence of wetlands favored by pool-breeding amphibians, some snakes, and rare turtles. Of particular importance are vernal pools—small, isolated wetlands generally unprotected by federal law—that reach high densities in southern Maine and provide habitat for a variety of reptiles and amphibians. These include the state endangered Blanding's turtle and threatened spotted turtle and many more common yet vulnerable reptile and amphibian species. At the same time, southern Maine is experiencing drastic development pressures. Because of the location of Wells NERR in southern coastal Maine, it represents a regionally important opportunity for conservation of reptiles and amphibian habitat. Wells NERR is itself an island in the midst of a rapidly developing coastline. Its diversity of wetland and upland habitats protect populations of reptiles and amphibians. As such, Wells NERR represents a valuable conservation opportunity in the struggle to maintain reptile and amphibian populations in the face of rapidly expanding human settlement. The purpose of this chapter is to review the biology of reptiles and amphibians of southern Maine with special emphasis on those known or suspected to occur in the Reserve, and the potential roles that Wells NERR may play in maintaining these populations.

THE SOUTHERN MAINE LANDSCAPE AS REPTILE AND AMPHIBIAN HABITAT

The current landscape of southern Maine is shaped by climate, geology, land use history and fire. Climatically, southern Maine is the most conducive part of the State for many exothermic vertebrates (reptiles and amphibians) due to latitude and moderating influence of the coast. Geologically, southern Maine was glaciated and this legacy has greatly influenced

the abundance and distribution of wetlands and in particular vernal pools. Isolated ice block depressions west of the inland marine limit tend to be deep, with long and yet seasonal hydroperiods and are consequently high quality vernal pools (Baldwin *et al.* 2006a). Closer to the coast—including the Wells area—clusters of vernal pools formed over glacial marine clays and provide multiple breeding habitats of varying hydroperiods important for maintaining a diversity of amphibians (Snodgrass *et al.* 2000).

Land use history has played an extremely important role in structuring reptile and amphibian habitats in southern Maine, as it has throughout New England (Foster *et al.* 2002). Farm abandonment during the last 50 years has resulted in general reforestation (Plantinga *et al.* 1999), and yet, as at Wells NERR, a patchy habitat of open fields, old fields, forests and wetlands remains. Several reptile species favor brushy or open habitats: the Eastern black racer (Maine endangered) is most frequently found in openings in the forested landscape (McCollough *et al.* 2003). As the land reverts to a forested state, many former farm ponds and borrow pits become functional wetland habitats. Spotted salamanders and wood frogs do not discriminate between vernal pools anthropogenic in origin and natural ones, provided the aquatic and surrounding forest environments have naturalized (Baldwin *et al.* 2006b).

At the same time as forests have recovered, pressure for housing development has resulted in sprawl: low density residential development combined with unrestricted road growth (Baldwin *et al.* in press-b). Residential growth rates in southern Maine towns were as high as 30% in the 1990's, indicating a trend towards continued growth and conversion of reforested lands to human uses.

These land use changes are particularly devastating for reptiles and amphibians. Many reptiles and amphibians are especially vulnerable to roads. Roads are attractive for exothermic vertebrates because they are heat islands. Snakes in particular are often killed while basking (Trombulak and Frissell 2000). Other reptiles and amphibians are at risk when they must cross roads during seasonal migrations. Turtles and amphibians, migratory yet slow moving, are at the greatest risk when they must move from one seasonal habitat (e.g., a vernal pool) to another (e.g., a forested wetland) (Forman and Deblinger 2000; Steen and Gibbs 2004).

Maine, like the rest of New England, has experienced rapid growth of the residential road network. Southern Maine in particular has experienced rapid unplanned growth of subdivision-type roads (cul de sacs and circles). The typical road building process is governed at the local government scale. The cumulative impact of building of so many small roads can be devastating. In Maine alone over the past two decades nearly 2,000 km of such roads

Family	Common Name	Scientific Name
Ambystomatidae (Mole Salamanders)	Blue SpottedXJefferson Salamander	*Ambystoma lateraleXjeffersonianum*
	Spotted Salamander	*Ambystoma maculatum*
Salamandridae (Newts)	Red Spotted Newt	*Notophthalmus viridescens*
Plethodontidae (Lungless Salamanders)	Redback Salamander	*Plethodon cinereus*
Bufonidae (Toads)	American Toad	*Bufo americanus*
Hylidae (Hylid Frogs)	Spring Peeper	*Hyla crucifer*
	Grey Tree Frog	*Hyla versicolor*
Ranidae (True Frogs)	Wood Frog	*Rana sylvatica*
	Green Frog	*Rana clamitans*
	Bull Frog	*Rana catesbeiana*
Emydidae (Terrapins or Pond Turtles)	Painted Turtle	*Chrysemys picta*
	Blanding's Turtle	*Emydoidea blandingii*
Chelydridae (Snapping Turtles)	Snapping Turtle	*Chelydra serpentia*
Colubridae (Typical Snakes)	Eastern Milk Snake	*Lampropeltis triangulum*
	Eastern Smooth Green Snake	*Opheodrys vernalis*
	Northern Red-bellied Snake	*Storeria occipitomaculata*
	Eastern Garter Snake	*Thamnophis sirtalis sirtalis*

Table 10-1: Wells NERR Reptiles and Amphibians. Sightings and highly probable habitat for common species.

were built (Baldwin *et al.* in press-b). Not only do the subdivision roads themselves threaten reptiles and amphibians, but the increased traffic onto existing roadways (e.g., primary and secondary highways) poses a major threat.

Another factor structuring the landscapes of southern Maine for reptiles and amphibians is the fire of 1947. This fire burned 15 townships but bypassed the Wells Reserve (Butler 1987). Nonetheless, the forest context for Wells is strongly influenced by this severe crown fire that may have rendered some areas less suitable for some amphibians (Baldwin *et al.* 2006b). Mole salamanders in particular seem to thrive in areas rich in advanced stage decayed wood and mature forests. They appear to be in lower densities in areas burned by the 1947 fire (Baldwin 2005). As a result of this recent fire, the habitat heterogeneity of southern Maine is great; Wells NERR as an unburned portion of the landscape in close proximity to burned townships may be important to study as a refugium for some amphibians.

Southern Maine is at a crossroads for reptiles and amphibians, and Wells NERR is poised to play a pivotal role in restoring and protecting these rare species. Suitable habitat left behind by farm abandonment and reforestation, a plethora of wetlands of many kinds and a high degree of state-level endemism has made southern Maine a focal area of conservation planning for these species. However, rapid rates of land use change and inadequate local control over growth and development threaten landscape integrity for reptiles and amphibians. As it has in the past, Wells NERR can reach beyond its borders to protect the watersheds and landscape context for its ecosystem processes and biodiversity.

VERNAL POOL HABITAT


A mass of spotted salamander eggs in a vernal pool. Photo Michele Dionne.

Vernal pools are common in the forested landscapes of southern Maine. They are small freshwater wetlands occurring in upland, typically forested settings. Closer to the coast, they are densely clustered while inland they tend to be more isolated, and larger (Baldwin 2005). They are used throughout the year by a variety of reptiles and amphibians for breeding, refuging (finding cover), and foraging. Vernal pools are "isolated wetlands" that are generally isolated hydrologically from the groundwater but, most importantly for understanding their ecology, they periodically dry out. Vernal pools in southern Maine are thus a class of *ephemeral* wetlands, the class of wetlands that receives the least legal protection. Several species of amphibian breeding in vernal pools in New England rely on the pools drying out at least once every 3-5 years (Colburn 2004). This cycle of inundation and drying out insures that fish and other predators of larval amphibians (e.g., bullfrogs and green frogs) cannot become established.

Importantly, reptiles and amphibians using vernal pools are concurrently dependent on habitat in the surrounding forested landscape. Blanding's and Spotted Turtles travel great distances migrating among over-wintering wetlands, breeding sites, and foraging and basking areas in vernal pools (Joyal *et al.* 2001). Garter and ribbon snakes live in the upland forests around vernal pools and forage in vernal pools for larval and adult amphibians (Baldwin *et al.* in press-b). Pool-breeding amphibians have an aquatic larval phase largely dependent upon aquatic conditions (see photos of egg masses and adult spotted salamander), and a terrestrial adult phase dependent largely on forest conditions. As juveniles and adults, their dispersal and migration patterns can carry them across many acres of wetland and upland habitat (Semlitsch 2000).

In southern Maine, no species more completely illustrates the need for habitat connectivity among wetlands and uplands than the wood frog. This species migrates hundreds of meters among spring breeding pools, summer

Common Name	Scientific Name	Status	MBLR	Webhannet	Ogunquit
Eastern Black Racer	*Coluber constrictor*	**SE**	**x**		**x**
Ribbon Snake	*Thamnophis sauritus septentrionalis*	**SC**	**x**	**x**	**x**
Wood Turtle	*Clemmys insculpta*	**SC**	**x**		
Spotted Turtle	*Clemmys guttata*	**ST**	**x**	**x**	**x**
Blanding's Turtle	*Emydoidea blandingii*	**SE**	**x**	**x**	**x**

Table 10-2: Sightings of rare reptiles and amphibians in Wells NERR watersheds. MBLR = Merriland River, Branch Brook, Little River. Status: SE = State Endangered, ST = State Threatened; SC = Special Concern. Source: Maine Department of Inland Fisheries and Wildlife.

forested wetland foraging areas, and upland hibernacula (Baldwin *et al*. 2006a). These linkages among aquatic, wetland and terrestrial environments illustrate the complexity of reptile and amphibian habitat conservation in rapidly developing southern Maine.

Maintaining Habitat in a Rapidly Developing Region

The dynamic nature of the southern Maine landscape is written at the Wells Reserve, where fields and forests in various stages of succession intermingle with freshwater wetlands. These heterogeneous conditions are ideal for maintaining an array of reptiles and amphibian species. In fact, the 1,600 acres at Wells NERR may play an important role in maintaining source populations for the Wells area. Wells NERR records indicate that 18 species have occurred within the reserve boundaries (Table 10-1). Maine Department of Inland Fisheries and Wildlife (MDIFW) records indicate that 5 rare reptile species have been found within the three main watersheds of Wells NERR (Merriland River, Branch Brook and Little River (MBLRO, Webhannet River, and Ogunquit River), only one of which (Blanding's Turtle) has so far been confirmed at the Reserve itself (Table 10-2).

Likewise, there are 17 mapped vernal pools within Wells NERR (Figure 18-1). Surveys of the breeding assemblages and habitat conditions of these pools were conducted in 1996 (Jamie Haskins, MDIFW unpublished data). In 2006, we surveyed the habitat conditions around these pools and conducted GIS analyses of landscape conditions (Table 10-3).

The vernal pools on the Wells Reserve are embedded in a typical New England landscape dominated by regenerating forest and old field. The pools range in depth from 10 to 60 cm. Three quarters of the pools are known to be amphibian breeding sites and three (numbered 2,4 and 7) may be significant breeding sites for wood frogs (Table 10-3). Seven are used by both primary indicator species: wood frogs and spotted salamanders. Most of the pools occur in an undeveloped context, meaning there is appreciable upland or non-breeding habitat quality around them even though some development is certainly present (Table 10-3; Figure 10-1).

Because pond turtles and pool-breeding amphibians migrate among breeding wetlands and non-breeding habitat crossing upland landscapes (Joyal *et al*. 2001), and because pool-breeding amphibian populations (individual pools) are loosely joined by juvenile dispersal (many pools constitute a "metapopulation") (Marsh & Trenham 2001) the pools at Wells NERR occur in a landscape context amenable to long term viability of reptile and amphibian populations. We might be able to say, with further research, that Wells NERR constitutes a functional vernal pool "landscape," increasingly rare in southern Maine.

Wells NERR has 18 confirmed species of reptile and amphibian and it is entirely possible that with more surveys Wells NERR will reveal populations of the additional species found in surrounding watersheds. Thus, Wells NERR represents not only an excellent conservation opportunity for reptiles and amphibians—an island in a sea of coastal rim development—it also represents an opportunity for long term research important for understanding population processes of wetland assemblages of reptiles and amphibians. In this sense, Wells NERR can be viewed as a "reference site" for understanding population processes in a developing landscape. As surrounding habitats become more fragmented from road building Wells NERR populations may be monitored to serve as a benchmark for assessing reptile and amphibian declines. The information gleaned from this kind of research is

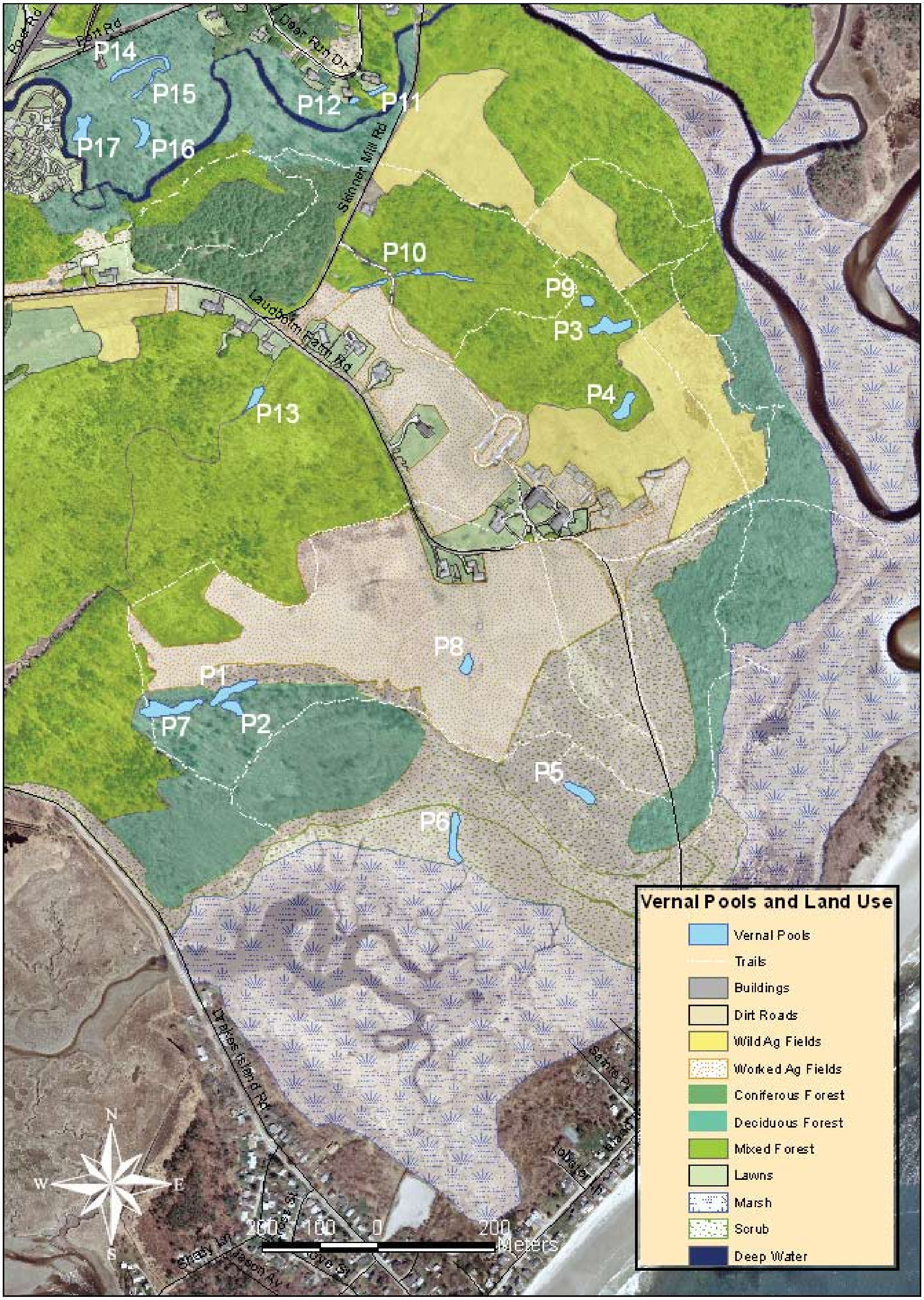


Figure 10-1: Vernal pool habitat and land use at Wells NERR. Map Dan Zeh.

A spotted salamander (Ambystoma maculatum). These elusive amphibians can be seen crossing roads on rainy spring nights, searching for vernal pools where they can mate and deposit egg masses. Photo James Dochtermann.

critical for design of conservation plans and for improving regulatory protections (Calhoun *et al.* 2003).

Vernal pools on protected lands such as Wells NERR are rare in southern Maine. Of 542 vernal pools assessed in a southern Maine gap analysis, only 2% occurred on protected lands (Baldwin 2005). Only half of southern Maine pools are protected by any means (wetland, wildlife and shoreland regulations; tree farms and other conservation easements). Half of the pools in southern Maine occur on private lands. Consequently, Wells NERR's conservation efforts at the watershed scale may be essential for protecting some of Maine's most threatened species. Strategies for protection need to include working with landowners through education and purchasing of additional easements, activities in which Wells NERR has long been engaged at the watershed scale.

A red eft (right) and a red spotted newt (left), placed on a log for viewing. The red eft is the juvenile terrestrial form of (Notopthalums viridescens) and develops into the adult aquatic form. Photo Wells NERR.

As with so many reserves across the nation, Wells NERR is becoming increasingly isolated by development. As with other reserves, managers must think beyond reserve boundaries to achieve within-reserve conservation goals. Perhaps the biggest regional impact on reptile and amphibian conservation would be felt through expanding the existing Wells NERR watershed level conservation activities. In particular, identifying and mapping critical habitats (e.g., vernal pools and Eastern black racer habitat), educating landowners, and working with land trusts to purchase easements in the three main Wells NERR watersheds would provide a region-scale service.

Species Accounts

The species accounts below were compiled from a variety of sources; most importantly Carpenter (1952), Ernst *et al.* (1994), Hunter *et al.* (1999), Petranka (1998) and McCollough *et al.* (2003). For engaging treatment of all Maine reptiles and amphibians, see Hunter *et al.* (1999).

Spotted Salamander (Ambystoma maculatum)

A southern Maine vernal pool indicator species, the spotted salamander also breeds in fishless ponds and oxbows of rivers. A large "mole" salamander, it can achieve 8 inches in length. Combined with its striking yellow-on-indigo coloration, it often surprises people with its dramatic beauty. Spotted salamanders, like all pool-breeding amphibians, have a strongly biphasic life history. Breeding occurs in pools where larval population dynamics are wholly controlled by aquatic parameters. Upon emergence, juveniles move into surrounding forests where they will live until sexual maturity. Adults live primarily underground, in more mature upland forests, where burrows (made by other animals) and root channels provide shelter and access to food. Slow moving during migration, Spotted salamanders are greatly at risk from southern Maine development.

Blue-Spotted X Jefferson Salamander (Ambystoma lateraleX A. jeffersonianum)

There is biological strangeness afoot in southern Maine forested wetlands. Two species common throughout New England—the Jefferson and Blue-spotted salamander—also hybridize and produce offspring that contain three or four sets of chromosomes (polyploidy). It is likely that in southern Maine, what is encountered most is the hybrid. These species have a similar life history to closely related spotted salamanders: they breed primarily in vernal pools and migrate to and from surrounding forested habitat. Also slow moving, they are at risk from automobiles.

Eastern Newt (Red-spotted Newt) (Notophthalmus viridescens)

Eastern newts are found in aquatic and terrestrial habitats throughout southern Maine. The Eastern newt is quite different from most other salamanders in North America because of its complete reliance on aquatic habitats as adults and contrasting complete reliance on terrestrial habitat as juveniles. Larvae generally develop into the "red eft" terrestrial stage (at left in photograph) during their first year, mostly inhabiting woodlands. They remain at this stage for 2-7 years. During this period they are usually bright orange with small, red dorsal spots, and have dry skin. Following this stage, they return to water and transform into breeding adults that are olive green, have small black as well as red spots, flattened tails, and slimy skin. Although the destruction of woodlands has resulted in the loss of some populations, this species remains abundant because of their ability to colonize many different types of aquatic habitats including anthropogenic water bodies.

Northern Redback Salamander (Plethodon cinereus)

Northern redback salamanders are very common, but they are not easily found unless you look under leaf litter or woody debris, or even inside very rotten wood during the driest and coldest parts of the year. This species has 3 different types that differ in coloration: red-back, lead-back, and erythristic. The red-back variety (most common) has dark sides and a wide, colored stripe running down the back that can be red, green, brown or yellow. Redbacks spend their entire life cycle on land. Eggs are laid under rocks or within rotting logs and are attended by adults. In southern Maine, redbacks are often found living in or near the giant pine stumps left behind by mid century logging. Because of their abundance and their role as predators of the tiny invertebrates that break down organic matter, redbacks are important for the whole ecosystem. Studies in New England forests have shown that because of sheer numbers and foraging activities redbacks may actually play a role in regulating greenhouse gasses, because they eat the organisms primarily responsible for releasing carbon dioxide from the forest floor.

American Toad (Bufo americanus)

The toad is one of the most common amphibians in southern Maine, although is also threatened by roads and habitat destruction. American toads (pictured below) have dry, warty-looking skin with large, prominent glands behind each eye containing a noxious substance that deters many would-be predators. Toad vocalizations are a sustained, dry trill. Toads breed in open shallow water. Juveniles and adults disperse into fields, forests, wetlands, yards, and are often found around gardens in highly developed areas. Their ability to use this wide variety of habitats no doubt contributes to their widespread distribution, but also their susceptibility to roads.

Gray Tree Frog (Hyla versicolor)

As its name implies, the gray treefrog is found in trees or shrubs rather than on the ground or in water. Gray tree frogs have green, brown or off-white colors blend in with their background, making it extremely difficult to find them on bark. Large toe pads allow them to adhere to vertical surfaces from which they call. Gray tree frog vocalizations are a repetitive, short, high-pitched trill with each one lasting less than half a second. They exist throughout the year in forested areas near ponds and wetlands including vernal pools.

Spring Peeper (Pseudacris crucifer)

Spring peepers are the smallest frog in Maine and are rarely seen, but often heard singing from their shrubby breeding wetlands – including many vernal pools. They

American toad (Bufo americanus). Photo Sue Bickford.

have a very loud, high-pitched breeding vocalization (the "peep"). Despite their cacophony, they are nearly impossible to spot. Look on the stems of cattails and shrubs emerging from the wetland. Peepers are tiny (max. length 1.5 in.) and become silent at the slightest disturbance to their wetlands. They are a pale golden-brown, with a noticeable cross pattern on the back. Research has shown that this species is negatively affected by the acidification of wetlands due to acid rain, because developing larvae have a harder time functioning in a lower pH.

Bullfrog (Rana catesbeiana)

Bullfrogs are the largest frogs in southern Maine, reaching up to 8" in length. They are green to brown and may be lightly mottled with darker colors, with smooth, not ridged, backs. Bullfrogs are voracious predators making them a problem species in regions of the United States where they have become invasive and eat native frogs in addition to just about any other animal they can fit into their capacious maws. They are aquatic frogs with a multiple-year tadpole stage, requiring lakes, slow-moving rivers, and permanent ponds for breeding. Like other frogs, they migrate among wetlands to forage and breed.

Green Frog (Rana clamitans)

The green frog is a very common species throughout southern Maine and can inhabit almost any type of wetland. Like bullfrogs, green frogs require aquatic habitats for breeding but also migrate among a variety of wetland types. In southern Maine they are frequently found foraging in vernal pools, especially after tadpoles have hatched, and they also eat large amounts of larval macroinvertebrates. In contrast to the bullfrog, green frogs have prominent ridges that run down the back starting at each eye. Their breeding vocalization sounds like a banjo string being plucked and they are often the first to report the presence of an intruder in their habitat, releasing a loud chirp and jumping in the water for safety. Juvenile green frogs migrate away from breeding ponds to moist forested wetlands to spend dry summer months where their habitat use overlaps with those of the wood frog.

Green frog (Rana clamitans) in duckweed. Photo Ward Feurt.

Wood frog (Rana sylvatica). Photo Robert Baldwin.

Wood Frog (Rana sylvatica)

The quintessential vernal pool frog, the wood frog emerges from hibernation in upper soil horizons of upland forests in the very early spring and travels overland to its breeding pools. Males congregate in vernal pools and make their famous "quacking" calls. Females join later and massive rafts of egg masses are formed (hundreds in particularly good vernal pools). After breeding, the adult wood frog travels as far as hundreds of meters to neighboring forested swamps where it spends the dry summer months. Wood frogs retain moisture during the summer by burying themselves in piles of moist leaves or sphagnum moss. Juveniles leave breeding pools by mid summer and disperse into surrounding woodlands. Because of the importance of surrounding forests for wood frogs, their movements place their populations at great risk from new road building.

Blanding's Turtle (Emydoidea blandingii)

Blanding's turtles have an unusual range. They are most numerous in the Midwest United States and then not found between the Midwest and eastern New York. Farther east still, there are isolated groups of populations in New Hampshire, Massachusetts, southern Maine, and

Blanding's turtle (Emydoidea blandingii). Photo Sue Bickford.

Nova Scotia. Their scattered distribution makes them a high-priority rare species in many states. Because of their size, brightly-speckled or streaked carapace, and yellow chin and throat, they would be quite noticeable if not for the fact that they spend most of their time submerged in wetlands. They prefer shallow wetlands with dense aquatic vegetation such as ponds (including larger vernal pools), marshes and small streams. Blanding's turtles migrate great distances between their upland nesting and wetland hibernating habitats, so roads that pass through their migration routes pose a serious threat to this species. Sightings in southern Maine should be reported to the Maine Department of Inland Fisheries and Wildlife (MDIFW).

Spotted Turtle (Clemmys guttata)

When viewed swimming through a tannin-rich vernal pool, all one can see of a spotted turtle is a constellation of yellow spots (see photo on first page of chapter). When held to the light, their full beauty comes out. Spotted turtles are blackish green with small, yellow spots on the carapace, head, neck and legs, and are small. They have a maximum carapace length of about 6 inches. They prefer shallow wetlands such as marshes, swamps and vernal pools—wetland habitats among which they migrate great distances. Spotted turtles are listed as rare in many states, including Maine, because of habitat loss and degradation. In southern Maine, numerous spotted turtles are killed while migrating across roads. Common predators such as raccoons and skunks also impact populations, as do illegal collections. Any sightings in southern Maine should be reported to MDIFW.

A snapping turtle (Chelydra serpentina) Photo Ward Feurt.

Painted Turtles (Chrysemys picta)

Painted turtles are the species we see all the time in and around ponds, lakes and slow-moving rivers. They are highly colorful with an attractive, smooth olive-green carapace that has red markings on the outer edges and scutes and red and yellow stripes on the head. Painted turtles are very common, doing well in a variety of aquatic habitats such as ponds, marshes, and shallow, slow-moving streams. As with snapping turtles, they are also known to live in brackish waters. They are often seen basking on top of logs or floating debris. Similar to all other turtle species in southern Maine, painted turtles need to migrate to sand or open dirt to nest. Therefore, populations can be negatively impacted by roads and increases in local nest predators such as raccoons and skunks.

Wood Turtle (Glyptemys insculpta)

Wood turtles have a brownish-gray carapace with a maximum length of 9.5 inches and bright orange skin on the legs and neck. New scutes on their carapaces can "build up" over time giving them a pyramidal appearance. This species is associated with riparian habitats where they typically spend the winter, spring and fall. In the summer, they move into other nearby wetland habitats such as oxbows and wet meadows and occasionally fields and pastures. Roads and habitat loss threaten wood turtle populations. Recent research done in Massachusetts also shows that individual wood turtles inhabiting riverine systems adjacent to agricultural lands have been destroyed by farm equipment when present at the edge of pasture and fallow fields.

Common Snapping Turtle (Chelydra serpentine)

A fearsome species of turtle if you grew up around ponds and lakes in southern Maine where the mythology was that the snapper would take toes off. The reality is the snapping turtle (see photo) rarely hurts anyone and is in fact declining. In many states such as Maine, snapping turtles are still harvested for their meat. As for other turtles, many are killed while crossing roads. Compounding their difficulties, females often nest on warm, sandy roadsides exposing hatching juveniles to road mortality. When not migrating, snapping turtles spend most of their time in muddy lakes, ponds and slow-moving rivers. They are also known to use brackish estuaries.

Milk snake (Lampropeltis triangulum) Photo Sue Bickford.

Eastern Milk Snake (Lampropeltis triangulum)

The Eastern milk snake (see photo) is handsomely patterned with three to five dorsal rows of brown or reddish blotches on a tan or gray background. When threatened it appears to mimic a timber rattlesnake by rattling its tail in dry leaves. It prefers mixed brush and meadows along woodlands. The milk snake hunts at night. It often lives near human habitation and is beneficial in controlling rodent populations. It also eats amphibians, small birds, insects, eggs and other snakes. The milk snake reaches the northeastern limit of its range in central Maine. It may be declining in southern Maine as old fields revert to forests and as roads fragment its habitat.

Smooth Green Snake (Liochlorophis vernalis)

The vivid green dorsum of the smooth green snake offers near complete camouflage in the grassy open habitats it prefers. The smooth green snake hunts during the day for insects, spiders and small vertebrates. Although it occurs most frequently in the settled portions of the State where historically there were abundant fields, numbers may be declining in southern Maine as farms revert to forest. The open areas of Wells NERR may provide particularly good habitat for the smooth green snake.

Eastern Garter Snake (Thamnophis sirtalis sirtalis)

The Eastern garter snake is the most widespread and abundant reptile in southern Maine. Its typical coloration includes three thin yellow or brown dorsal stripes. It is easily confused with the ribbon snake which has a longer tail and crisper stripes. The garter snake is the earliest snake to emerge from hibernation in spring. Garter snakes are important to southern Maine aquatic and terrestrial food webs. Vernal pools are favored habitats, where they eat adult and larval amphibians. Garter snakes are themselves an important food source for hawks, skunks, foxes and other snakes.

Eastern Ribbon Snake (Thamnophis sauritus)

The Eastern ribbon snake is a slender snake boldly marked with three bright yellow or buff stripes against a dark background. Its long slim tail, one third the length of its body, distinguishes it from the garter snake. The ribbon snake is semi-aquatic. Amphibians, especially metamorphosing tadpoles, make up the bulk of its diet, supplemented by insects, spiders and fish. It reaches the northeastern limit of its range in central Maine. However, its favored habitat, outwash plain pond shores, occurs mostly in York and Cumberland Counties. It is especially threatened by the loss and degradation of wetlands, including vernal pools and their surrounding uplands, which provide its main food source.

Eastern Black Racer (Coluber constrictor)

The Eastern black racer (pictured at end of chapter) is a long, slender, black snake named for its speed. Juveniles, heavily blotched at birth, lose their patterning as they grow. Racers hunt diurnally for invertebrates and other small vertebrate animals. This is a circumstance where the scientific name is not descriptive: they kill by bite rather than constriction. If pursued, a racer will often flee upward into shrubs or branches, and will fight fiercely if cornered. The only substantial population occurs in dry brushy habitat in Wells and Kennebunk, although sightings have been reported from other towns in York and Oxford Counties. Because of its territoriality and limited

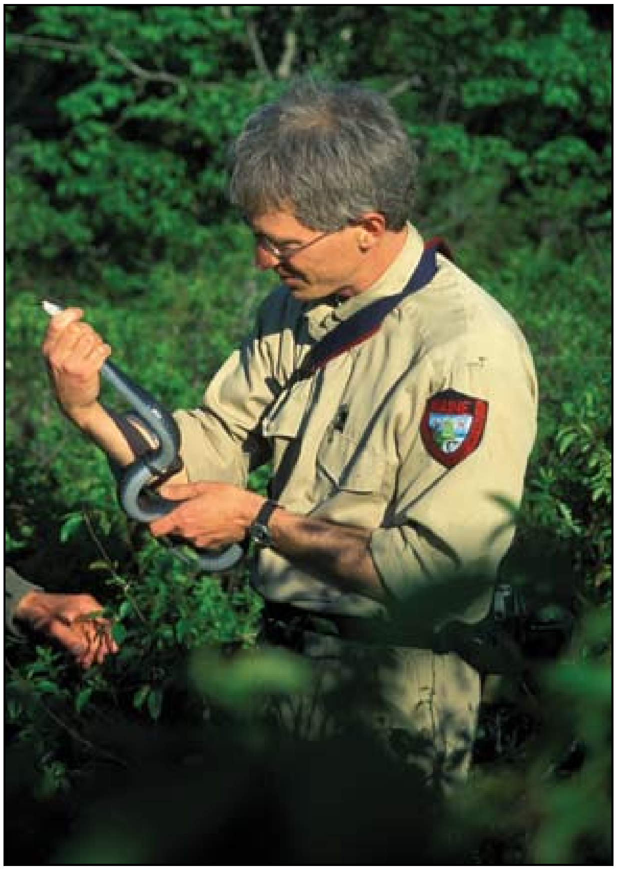
Vernal Pool #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Totals**
Depth (m)	0.3	0.6	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0.5	0.3	0.5	0.1	0.3	0.4	0.4	0.4	.34 ave. depth (m)
Presence Aquatic Macrophytes (Y/N)	N	Y	N	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	Y = 5, N = 12
Estimated number of egg masses for amphibian indicator species																		Total estimated number of egg masses
Wood Frog	20	40	5	150	20		50		2	1	10		7	10				315
Spotted Salamander			15	25					1	2	4	3	8	11		8		77
Relative frequencies (%) of upper canopy trees in surrounding habitat																		Total relative frequency (%) of upper canopy trees for all vernal pools
Balsam Fir													3.0%					0.2%
Black Birch			3.9%	18.4%	10.0%									8.6%	10.7%	10.7%	3.9%	4.1%
Paper Birch			26.9%	12.2%	20.0%	15.2%			2.6%	3.8%	18.2%	11.1%	12.1%	28.6%	6.7%	17.9%	26.9%	12.6%
Red Maple	69.2%	63.2%	26.9%	30.6%	70.0%	84.9%	46.7%		12.8%	13.2%	27.3%	11.1%	42.4%	22.9%	31.1%	14.3%	26.9%	37.1%
Red Oak	23.1%	21.1%	25.0%	20.4%			26.7%		61.5%	15.1%	27.3%	66.7%	27.3%	40.0%	51.1%	57.1%	25.0%	30.5%
Red Spruce				18.4%					10.3%	30.2%								3.7%
Sugar Maple													6.1%					0.4%
White Pine	7.7%	15.8%	17.3%				26.7%		12.8%	17.0%	27.3%	11.1%	9.1%				17.3%	10.1%
Yellow Birch										20.8%								1.3%
Immediate surrounding habitat containing hayfield or landscaped land (Y/N)	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	N	N	N	N	N	Y = 5, N = 12
Land use/cover (%) cover within 200m of vernal pools																		Total land use (%) coverage within 200m buffers for all vernal pools
Lawns				1.1%				3.8%		4.8%	3.7%	3.6%	7.9%	14.7%	11.7%	9.9%	15.7%	4.6%
Roads and Surfaces			0.2%	2.0%				0.6%		3.9%	5.4%	5.5%	3.4%	8.6%	5.7%	4.2%	9.0%	2.9%
Dirt Roads				0.7%				0.3%						1.7%	1.5%	0.5%	0.6%	0.3%
Buildings				1.9%				0.7%		1.0%	2.0%	2.1%	1.1%	2.0%	1.4%	1.1%	2.2%	0.9%
Inactive Farmland	25.5%	22.2%	0.5%	12.3%	7.4%	7.6%	14.5%	63.4%					4.7%					9.0%
Active Farmland			33.0%	45.4%					26.4%	10.8%	19.8%	16.3%						8.8%
Mixed Forest	27.2%	20.1%	63.4%	33.4%			47.0%		73.6%	12.1%	31.9%	26.2%	76.8%	11.9%	13.8%	14.0%	16.9%	27.1%
Conifer Forest										52.5%	8.3%	11.7%	5.0%	4.5%	4.4%	9.7%	0.9%	6.7%
Deciduous Forest	41.9%	51.9%	2.7%	3.3%	8.2%	8.8%	33.9%	7.3%		13.9%	22.8%	28.3%		49.6%	54.5%	53.9%	47.6%	25.2%
Marsh			0.3%		0.5%	35.3%												2.2%
Shrubs	5.5%	5.8%			83.9%	48.3%	4.6%	23.9%		0.2%	2.4%	2.5%	1.1%	1.9%	1.4%	1.7%	2.5%	10.8%
Deep Water (barrier)										0.7%	3.7%	3.7%		5.1%	5.6%	5.0%	4.6%	1.6%

Table 10-3: Characteristics of vernal pools at Wells NERR. Amphibian breeding data collected April 1997 by Jamie Haskins (MEDIFW), habitat data collected November 2006 by T. Dexter, and land use data remotely colleted and analyzed Fall 2006 by D. Zeh.

range the black racer is particularly vulnerable to sprawl and habitat degradation.

Northern Red-bellied Snake (Storeria occipitomaculata)

The Northern red-bellied snake is a small secretive reptile with variable coloration most often with a red belly, brown or slate gray dorsum and three tan spots on the nape of the neck. They are habitat generalists, occurring in most southern Maine areas. They can be found hiding beneath rocks, bark and wood. Southern Maine gardeners should encourage this species: slugs make up as much as 90% of its diet. The geographical range of the red-bellied snake includes almost all of Maine.



MDIFW biologist holding a rare Eastern black bacer of Southern Maine. Photo Parker Schuerman.

References

Baldwin, R.F. 2005. Pool-breeding amphibian habitat use and conservation in southern Maine's urbanizing landscape. Dissertation. Ecology and Environmental Sciences. University of Maine, Orono, ME. 163 pp.

Baldwin, R.F., A.J.K. Calhoun, and P.G. deMaynadier. 2006a. The significance of hydroperiod and stand maturity for pool-breeding amphibians in forested landscapes. Canadian Journal of Zoology 84:1604-1615.

Baldwin, R.F., A.J.K. Calhoun and P.G. deMaynadier. 2006b. Conservation planning for amphibian species with complex habitat requirements: a case study using movements and habitat selection of the wood frog *Rana sylvatica*. Journal of Herpetology 40:443-454.

Baldwin, R.F., S.C. Trombulak, M.G. Anderson and G. Woolmer. In Press-a. Projecting transition probabilities for regular public roads at the ecoregion scale: a Northern Appalachian/Acadian case study. Landscape and Urban Planning.

Baldwin, R.F., P.G. deMaynadier and A.J.K. Calhoun. In Press-b. Wood frog *Rana sylvatica*: predation. Herpetological Review.

Butler, J. 1987. Wildfire loose: the week maine burned. Down East Books, Camden, ME

Calhoun, A.J. K., T.E. Walls, S.S. Stockwell and M.M. McCollough. 2003. Evaluating vernal pools as a basis for conservation strategies: a Maine case study. Wetlands 23: 70-81.

Carpenter, C.C. 1952. Comparative ecology of the common garter snake (*Thamnophis sirtalis sirtalis*), the ribbon snake (*Thamnophis sauritus*) and Butler's garter snake (*Thamnophis butlerii*) in mixed populations. Ecological Monographs 22: 235-258.

Colburn, E.A. 2004. Vernal pools: natural history and conservation. Woodward Publishing Company, Blacksburg, VA.

Ernst, C.H., J.E. Lovich and R.W. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington D.C.

Forman, R.T.T. and R. D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology 14: 36-46.

Foster, D.R., G. Motzkin, D. Bernardos and J. Cardoza. 2002. Wildlife dynamics in the changing New England landscape. Journal of Biogeography 29: 1337-1357.

Hunter, M.L., A.J.K. Calhoun and M.M. McCollough. 1999. Maine amphibians and reptiles. University of Maine Press, Orono, ME. 252 pp.

Joyal, L., M.M. McCollough and M.L. Hunter Jr. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. Conservation Biology 15:1755-1762.

Marsh, D.M. and P.C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology 15: 40-49.

McCollough, M.M., C. Todd, B. Swartz, P.G. deMaynadier and H. Givens. 2003. Maine's endangered and threatened wildlife. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 117 pp.

Petranka, J.W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington D.C. 587 pp.

Plantinga, A.J., T. Mauldin and R.J. Alig. 1999. Land use in Maine: determinants of past trends and projections of future changes. Research paper. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64: 615-631.

Snodgrass, J.W., M.J. Komoroski, A.L. Bryan Jr. and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod, and amphibian species richness: implications for wetland regulations. Conservation Biology 14: 414-419.

Steen, D.A. and J.P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology 18: 1523-1739.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18-30.

Chapter 11

Fish

Michele Dionne and James Dochtermann

The ecology of fish populations and communities using the marsh-estuarine ecosystems in the Gulf of Maine has been little explored. Many intriguing questions are waiting to be posed and investigated, especially in the numerous estuaries that characterize the Seacoast Region (southcoast Maine and coastal New Hampshire), of which the Reserve's estuaries are representative. Nearly 50% of the salt marsh acreage along the Gulf of Maine coastline is located on the coast of Maine (Jacobson *et al.* 1987), more than twice that of any other Gulf of Maine coastal state, and more than any state north of New Jersey. Given the important place of salt marshes in the coastal landscape, it is surprising how little we know of the role that salt marsh ecosystems play in supporting the fish community of the Gulf of Maine. Fish distribution has been studied in a handful of marsh-estuarine ecosystems (Lamborghini 1982, Roman 1987, Murphy 1991, Ayvazian *et al.* 1992, Doering *et al.* 1995, Cartwright 1997, Lazzari *et al.* 1999, Dionne *et al.* 1999, Eberhardt 2004, Morgan *et al.* 2005a,b, Dionne *et al.* 2006, Konisky *et al.* 2006). Fish diets and food webs have been studied in yet fewer marshes (Lamborghini 1982, Cartwright 1997, Deegan and Garritt 1997). Nursery function for post-larval and juvenile fishes and foraging habitat value for adult marine fish are poorly understood.

There is a substantial body of ecological research that has focused on fish and decapod crustaceans (together referred to as nekton) in more southerly marshes (New Jersey to Georgia; see Day *et al.* 1989, Rozas 1995, Kneib 1997, and Weinstein and Kreeger 2000, for reviews). Nursery and adult foraging functions have been described for the Virginian coastal province (classification of Cowardin *et al.* 1979; Smith *et al.* 1984; Rountree and Able 1992a,b; Rountree and Able 1993; Szedlmayer and Able 1996, Griffin and Valiela 2001, Currin *et al.* 2003, Litvin and Weinstein 2004, Wozniak *et al.* 2006); Carolinian (Shenker and Dean 1979, Weinstein 1979, Bozeman and Dean 1980, Weinstein and Walters 1981, Rogers *et al.* 1984, Hettler 1989, Kneib 1993, Kneib and Wagner 1994, Miltner *et al.* 1995, Irlandi and Crawford 1997), and Louisianan coasts (Boesch and Turner 1984, Felley 1987, Deegan *et al.* 1990, Deegan 1993, Peterson and Turner 1994, Minello and Webb 1997). The results of this work do not directly apply to the Gulf of Maine, given its dramatically different climate, geology, marsh plant communities, substrates and tides, not to mention species assemblage.

Fifty-seven fish species have been identified within the Reserve's estuaries and adjacent waters of the Wells Embayment (Table 11-1). These species represent three life history patterns that we have simplified from the seven patterns described by Ayvazian *et al.* 1992 (following the classification of McHugh 1967): **resident**, **migratory** (anadromous and catadromous), and **transient**. Estuarine residents are species that spawn and spend a significant part of their life in the estuary. Migratory fish are those with an anadromous or catadromous life history. Here the transient life history habit includes the "spawner" (marine species that spawn in estuaries), "nursery" (marine species that spawn in ocean waters but use the estuary as a nursery), and "marine" (marine fish that visit the estuary as adults) classifications (Table 11-1).

Wells NERR and affiliated scientists have investigated nekton distribution and abundance of both back-barrier and fringing marshes in the region. Early studies focused on basic species surveys in the Webhannet and Little River estuaries, followed by assessments of fish foraging; nekton response to marsh restoration, land use, and oil contamination; and trophic transfer of mercury. In the overview that follows, we present synopses of these projects, as well as relevant studies from other Gulf of Maine marsh-estuarine ecosystems.

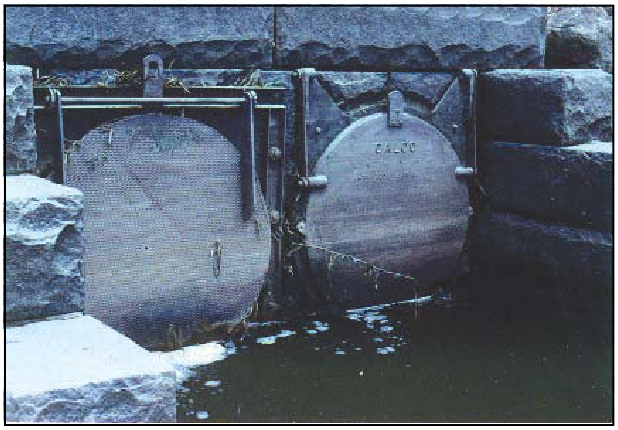
RESEARCH OVERVIEW

A Regional Assessment of Salt Marsh Restoration and Monitoring in the Gulf of Maine (Konisky et al. 2006)

Most salt marsh ecosystems in the Gulf of Maine have been hydrologically fragmented, especially by road crossings with undersized and poorly placed culverts and tide gates (pictured). To evaluate the response of hydrologically altered salt marsh systems to restoration, data were compiled from 36 Gulf of Maine salt marsh restoration and reference sites (Fig. 11-1) monitored voluntarily using a standardized protocol (Neckles and Dionne 2000, Neckles *et al.* 2002). Protocol indicator variables measure aspects of soils, hydrology, vegetation, birds and nekton. While soils were monitored at 78% of paired restoration and reference sites, and vegetation at 89% of sites, nekton variables were measured much less frequently (species richness – 56%, density – 36%, length – 47%, biomass – 36%). In addition, at many sites, sampling methods provided only relative abundance measures of a subset of species. Twenty-four nekton species (18 fish, 3 crabs and 3 shrimp) were identified from the pooled data: 20 species from reference sites, 13 from pre-restoration sites and 13 from restoration sites. Seven of these species were found only at reference sites, and three only at restored sites. Mean species richness was similar among reference (3.5), pre-restoration (3.0) and reference sites (3.6). There were no significant differences in fish density for pre-restoration sites, sites 1 year post-restoration, and sites 2 or more years post-restoration (5 – 6 fish m^{-2}). The fish monitoring protocol was revised in 2005 to simplify the sampling gear and encourage greater protocol implementation (Taylor 2007).

Developing an Index of Tidal Wetland Health in the Gulf of Maine using Fish as Indicators. (Dionne et al. 2006)

Fringing salt marshes are widespread throughout coastal Maine, yet their narrow dimensions have prevented adequate mapping and quantification. In Casco Bay, fringing marsh habitat is increasingly subject to upland runoff and other changes associated with intense shoreland development. A set of 12 fringing marshes were selected in a stratified random design to assess nekton response



Tide gates deprive many acres of former salt marsh from tidal flow. Photo Michele Dionne.

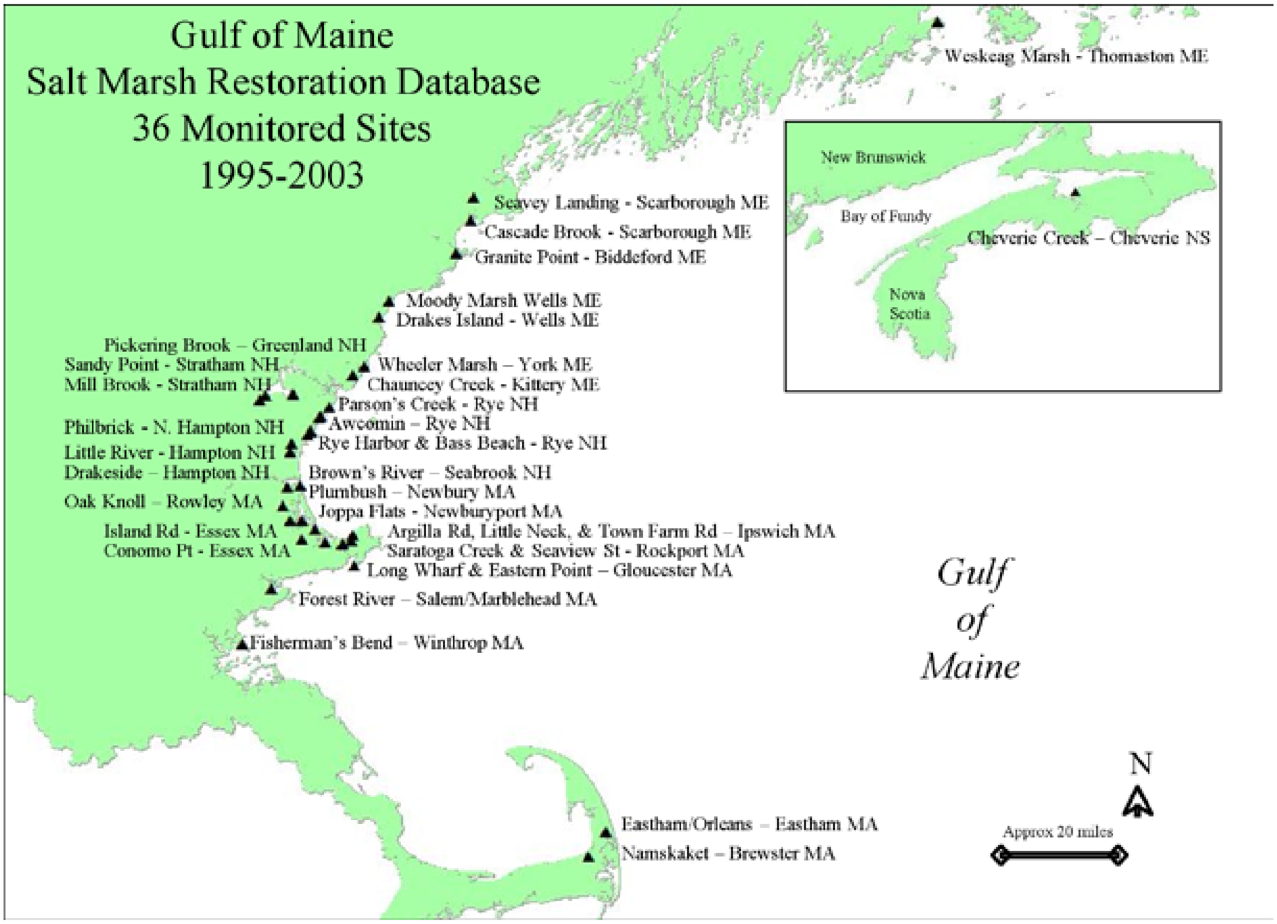


Figure 11-1: Study sites for regional assessment of salt marsh restoration (Konisky *et al.* 2006).

to the effects of adjacent land use, with 4 replicate sites representing low, intermediate and high levels of land use impact. Species identity, density, and biomass were used to develop candidate metrics for a tidal marsh index of biotic integrity. Twenty-two species were identified, and individuals counted and weighed in fyke net samples from marsh segments of known area (see photo of fyke net). Twenty candidate metrics were tested for trends related to impact level. Four metrics showed a positive response to impact: green crab % biomass, *Fundulus* biodensity, *Fundulus* density, tomcod % biomass. Ten metrics revealed a negative trend: shrimp % biomass, tomcod biodensity and density, piscivore biodensity and density, total piscivores, other fish (i.e.,non-*Fundulus*) biodensity and density, total other fish, and native species richness. In future work, these metrics will be further tested with additional fish data and related to a more quantitative assessment of land use for the 12 sites.

An Estimate of the Economic Value of Southern Maine Tidal Wetlands to the Maine Commercial Groundfish Industry (Hayes 2005)

Explicit knowledge of the economic value to society of ecosystem services often provides motivation for investment in better management of the ecosystems concerned, to ensure the continued flow of economic benefits. This study estimates the economic value of tidal wetlands in southern Maine (from approximately Damariscotta to the New Hampshire border) to the commercial ground fishing industry of Maine. The dependence of scientific trawl biomass (from the Maine and New Hampshire Inshore Trawl Survey and the NOAA / NMFS / Northeast Fisheries Science Center's Bottom Trawl Survey) on the nearest wetland area was determined using linear regression. This dependence was used to estimate the commercial fisheries' production function dependence on (the marginal product of) those same wetland areas. This was used to obtain an estimate of the economic value of those wetlands to the industry and society. Marginal

Scientific Name	**Common Name**	Life history	Maine & Seacoast NH [1]	Maine & Seacoast NH [2]	Herring River, MA [3]	Little River, ME [4]	Little River, ME [5]	Wells Harbor, ME [6]	Webhannet River, ME [7]	Kennebec Point, ME [8]	Bass Harbor Marsh, ME [9]	York River, ME [10]	Casco Bay, ME [11]	Montsweag, ME [12]	Piscataqua River, NH [13]	Saco River, ME [14]	Saco River, ME [15]	Kennebec River, ME [16]
Alosa aestivalis	Blueback Herring	m(a)			x	x		x		x							x	x
Alosa mediocris	Hickory Shad	m(a)			x												x	
Alosa pseudoharengus	Alewife	m(a)			x	x		x		x		x	x	x			x	x
Alosa sapidissima	American Shad	m(a)	x			x											x	
Brevoortia tyrannus	Atlantic Menhaden	t			x	x					x							
Clupea harengus	Atlantic Herring	t	x			x		x		x	x	x	x	x				
Ammodytes americanus	Sand Lance	t				x				x		x				x		
Anguilla rostrata	American Eel	m(c)	x	x	x	x	x	x			x	x	x	x			x	x
Apeltes quadracus	Fourspine Stickleback	r	x	x	x	x	x	x	x	x	x	x	x	x		x		
Gasterosteus aculeatus	Threespine Stickleback	r	x			x	x	x	x	x	x	x	x	x				
Gasterosteus wheatlandi	Blackspotted Stickleback	r	x			x	x	x	x	x	x			x				
Pungitius pungitius	Ninespine Stickleback	r	x	x		x	x	x	x	x	x	x	x	x				
Cyclopterus lumpus	Lumpfish	t				x				x		x						
Liparis atlanticus	Seasnail	t				x												
Decapturus macarellus	Mackerel Scad	t								x								
Fundulus heteroclitus	Mummichog	r	x	x	x	x	x	x	x	x	x	x	x					
Fundulus majalis	Striped Killifish	r	x	x	x					x								
Gadus morhua	Atlantic Cod	t								x								
Microgadus tomcod	Atlantic Tomcod	t	x			x	x	x		x		x	x	x	x	x		
Pollachius virens	American Pollock	t								x	x	x	x					
Urophycis chuss	Red Hake	t								x		x				x		
Urophycis tenuis	White Hake	t				x		x		x			x	x				
Menidia beryllina	Inland Silverside	r						x										
Menidia menidia	Atlantic Silverside	r	x	x	x	x	x	x	x	x	x	x	x	x	x			
Menidia peninsulae	Tidewater Silverside	r			x													
Morone americana	White Perch	t	x		x					x		x					x	x
Morone saxatilis	Striped Bass	t	x			x				x		x					x	x
Mugil cephalus	Striped Mullet	t				x												
Hemitriperus americanus	Sea Raven	t								x								
Myoxocephalus aeneus	Grubby Sculpin	t				x						x			x			
Myoxocephalus octodecimspinosus	Longhorn Sculpin	t				x				x								
Myoxocephalus scorpius	Shorthorn Sculpin	t								x								
Osmerus mordax	Rainbow Smelt	m(a)				x		x		x		x			x			
Peprilus tricanthus	Butterfish	t				x												
Petromyzon marinus	Sea Lamprey	m(a)				x											x	x
Pomatomus saltatrix	Bluefish	t			x	x				x		x	x					
Pholis gunnellus	Rock Gunnell	r				x										x		
Pleuronectes ferrugineus	Yellowtail Flounder	t									x							
Pleuronectes putnami	Smooth Flounder	t										x	x	x				
Pseudopleuronectes americanus	Winter Flounder	t		x	x	x	x			x		x	x	x	x			
Rajidae sp.	Skate	t													x			
Scopthalmus aquosus	Windowpane	t				x												
Salmo salar	Atlantic Salmon	m(a)				x											x	x
Salmo trutta	Brown Trout	m(a)				x						x						
Salvelinus fontinalis	Brook Trout	m(a)				x					x	x						
Scomber scombrus	Atlantic Mackerel	t			x	x												
Sphyraena borealis	Northern Sennet	t																
Syngnathus fuscus	Northern Pipefish	t			x	x		x		x	x	x		x				
Tautogolabrus adspersus	Cunner	t					x					x		x	x			

r = resident species, t = transient species, m(a) = marine anadromous species, m(c) = marine catadromous species

Table 11-1: Fish species list for Wells NERR and other Maine estuaries. Note that these studies used a variety of fish sampling methods and a range of sampling effort.

Table 11-1: Footnotes

1. Dionne, M., F.T. Short, and D.M. Burdick. 1999. Fish utilization of restored, created and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.

2. Wells National Estuarine Research Reserve. 2005. Unpublished data.

3. Roman, C.T., 1987. An evaluation of alternatives for estuarine restoration management: the Herring River ecosystem (Cape Cod National Seashore). Center for Coastal and Environmental Studies, National Park Service Cooperative Research Unit, Rutgers, The State University of New Jersey, New Brunswick.

4. Orringer S., Reid S., Sullivan N. 1995. A survey of migratory fishes in the Little River estuary and its watershed. Draft final data report, submitted to the Institute of Museum Services, Silver Spring, Maryland. 34 pp.

5. Murphy, S.C. 1991. The Ecology of Estuarine Fishes in Southern Maine High Salt Marshes; Access Corridors and Movement Patterns. Masters Thesis. University of Massachusets. 103 pp.

6. Ayvazian, S.G., L. Deegan, and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian Zoogeographic Provinces. Estuaries 15(3): 368-383.

7. Murphy, S.C. 1991. The Ecology of Estuarine Fishes in Southern Maine High Salt Marshes; Access Corridors and Movement Patterns. Masters Thesis. University of Massachusets. 103 pp.

8. Lazzari, M.A., and six coauthors. 1996. Seasonal and annual variation in abundance and species composition of nearshore fish communities in Maine. Maine Department of Marine Resources, West Boothbay Harbor.

9. Doering, P.H., C.T. Roman, L.L. Beatty, A.A. Keller, and C.A. Oviatt. 1995. Water quality and habitat evaluation of Bass Harbor Marsh-Acadia National Park, Maine. Technical Report NPS/NESORNR/NRTR95-31. U.S. Department of the Interior, National Park Service, New England System Support Office, Boston.

10. Dionne, M., J. Dochtermann, and A. Leonard. 2006. Fish communities and habitats of the York River watershed. Wells National Estuarine Research Reserve. Wells, ME. 63 pp.

11. Morgan, P.A., M. Dionne, R. MacKenzie, and L. Curci. 2005. Ecological functions and values of fringing salt marshes susceptible to oil spills in Casco Bay, Maine. Report submitted to the Maine Oil Spill Advisory Committee. 61 pp.
    and
    Morgan, P.A., L. Curci, C. Dalton, and J. Miller. 2005. Assessing the health of fringing salt marshes along the Fore River and its tributaries. Natural Resource Damage Trustees, Maine Department of Environmental Protection, Portland, ME. 45 pp.

12. Yoder, C. 1972. The pelagic and demersal finfish of the Montsweag Brook Estuary. Unpublished report. 91 pp.

13. Wells National Estuarine Research Reserve. 2002. Unpublished data.

14. Wells National Estuarine Research Reserve. 2002. Unpublished data.

15. Saco River Coordinating Committee. 2001. 2000 Annual Report Saco River Fish Passage Assessment Plan. 41 pp.

16. Brown, M.E. 2002. Anadromous fish restoration in the Androscoggin River Watershed. 2001 Report on the Operation of the Brunswick Fishway FERC #2284, Maine Department of Marine Resources Stock Enhancement Division.

values (dollars per square meter) for seven commercial fish species and five wetland types successfully modeled, ranged from zero to \$14.31 m^{-2}. A conservative estimate of the total value flowing to society from the wetlands studied through this means was estimated to be over \$32 million per year (2003 U.S. dollars).

Ecological Functions and Values of Fringing Salt Marshes Susceptible to Oil Spills in Casco Bay, Maine (Morgan et al. *2005)*

Fringing marshes are abundant intertidal habitats along much of Maine's coast. In terms of vegetation, they are similar to the channel edges of much larger back-barrier marshes such as those at Wells NERR, with a sloping low marsh shoulder grading into high marsh. Rather than forming a broad high marsh plain, the fringing marsh hugs the upland edge in a narrow band, typically 10 m to 30 m wide. Because of their narrow width, fringing marshes are greatly under-represented by coastal wetland mapping programs, and consequently have received little attention by scientists or managers. The plant, invertebrate and nekton communities were surveyed at 9 fringing marsh sites in Casco Bay, Maine, in the vicinity of Portland Harbor, Northern New England's largest oil shipping port. The survey established baseline data for use in damage assessment, should fringing marshes be affected in the event of an oil spill. Five marsh resident fish species were present at all sites over two years (2002 – 2003): mummichog, Atlantic silverside, and three stickleback species (3-spine, 4-spine, 9-spine), as well as juvenile smooth flounder, a marine transient. Other marine transients were Atlantic herring, winter flounder, and hake (red / white). Resident biomass density exceeded that of marine transients by fourfold. Migratory species were present at most sites in both years: American eel, alewife, rainbow smelt and tomcod. Mean biomass densities in g m^{-2} for the 2002 – 2003 pooled data was $\bar{x}$ = 0.21 ±0.061 SE for residents, $\bar{x}$ = 0.05 ±0.035 SE for transients, and $\bar{x}$ = 0.13 ±0.045 SE for migratory species. The non-native green crab was present at all sites on all dates, and at much greater biomass than the other macrocrustaceans (rock crab, jonah crab, hermit crab, and sand shrimp). In fact, the green crab biomass density was tenfold higher than that of the resident fishes at $\bar{x}$ = 2.24 ±0.74 SE for the pooled data. In a 2004 follow up study (Morgan *et al.* 2005b) comparing 3 fringing marsh sites that had been contaminated in a 1996 oil spill with three reference marshes, 10 fish and 2 crustacean species were collected, all of which were present in the 2002 – 2003 survey. Interestingly, American eel, tomcod, and smooth flounder were collected only at reference sites. The sand shrimp also was better represented at the reference than at the impact sites. Green crab biomass density was greater in the reference than in the impact sites (≈ 1.7 vs. ≈ 0.8 g m^{-2}), but fish biomass density in the impacted sites was twice that of the reference sites (≈ 0.4 vs. ≈ 0.2 g m^{-2}). Fish at the impact sites may have experienced an increase in growth due to release from green crab predation risk.

Fyke net set for fish sampling in a Casco Bay fringing marsh. Photo Michele Dionne.

Bioaccumulation of Metals in Intertidal Food Webs (Chen et al. *2004)*

Numerous New England estuaries have been contaminated by mercury (Hg), but the potential movement of mercury through estuarine food webs has not been investigated (Fig. 11-2). A pilot study was conducted to characterize Hg bioaccumulation in intertidal food webs in four different Gulf of Maine sites: Great Bay, NH (Adams Point, Porstmouth Naval Shipyard), Webhannet Estuary ME, and Mount Desert Island ME), which differ in physical, chemical, and land use characteristics. For each site, the bioaccumulation and trophic transfer of Hg in the resident and transient benthic, epibenthic, and nektonic species inhabiting the intertidal and subtidal portions of these systems was quantified. Hg bioaccumulation was measured at multiple trophic levels and relative trophic position and food source was estimated using stable isotopes ($\delta^{15}N$ and $\delta^{13}C$). Results of the study show different patterns of Hg bioaccumulation and trophic transfer depending on the site and taxonomic group. All species measured for Hg from the Webhannet Estuary contained < 0.02 µg gww^{-1}, while values ranged up to ≈ 0.10 µg gww^{-1} in Great Bay. However, differences in trophic position or food source did not predict Hg bioaccumulation. Results suggest that both benthic and pelagic food webs may be important pathways for Hg trophic transfer in estuarine systems.

Fish Versus Human Corridors: The Impacts of Road Culverts on Nekton Community Composition and Movement in New England Salt Marshes (Eberhardt 2004)

Many Gulf of Maine salt marshes are transected by at least one transportation crossing (e.g. road, railroad, causeway). Marsh channels are often blocked; and undersized, poorly placed, culverts provide the only hydrologic connection from one side of the crossing to the other. This study investigated fish movement through road culverts in salt marsh creeks at several seacoast sites including the Wells NERR. Fish were collected upstream of tidally restrictive and tidally restored culverts, as well as in paired reference marsh creeks, in order to assess the effects of culverts on upstream nekton assemblages. Similar densities of fish were found throughout the marshes, although significantly lower densities of the sand shrimp (*Crangon septemspinosa*), were encountered. This may be evidence that culverts pose a migration barrier to shrimp. Fewer transient fish species were encountered upstream of culverts, suggesting that they impeded nekton movement. A study using a mark-recapture technique with the common mummichog (*Fundulus heteroclitus*) was carried out in tidally restricted, restored, and reference salt marshes to assess the impact of culverts on the mummichog's movement in creeks. Results indicate that small culvert size and increased water velocity considerably reduced rates of mummichog passage (Fig. 11-3), though decreased light intensity had no impact on movement. Eberhardt concludes that the presence of impounded upstream subtidal habitats, along with increased water velocity may cause a drop in nekton movement between the downstream and upstream portions of the marsh creek, leading to segregated populations. Culvert restoration may lead to increased movement of resident fish, and ultimately an increase in fish production relay from salt marshes to coastal waters.

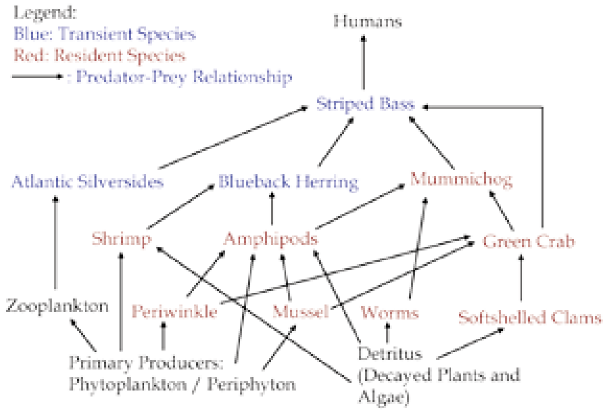


Figure 11-2: Food web indicating key species thought to be involved in trophic transfer of mercury (adapted from Chen *et al.* 2004).

Fish Utilization of Restored, Created and Reference Salt Marsh Habitat in the Gulf of Maine (Dionne et al. 1999)

Successful salt marsh restoration depends on adequate evaluation of restoration response. Fish utilization of restored and created marshes in New Hampshire and Maine (two created and four tidally restored marshes, including the Reserve's Drakes Island marsh) was compared to adjacent reference marshes. Fifteen fish and 4 crustacean species were collected from 13 marsh areas. This study provided the first density estimates for fish utilization of vegetated salt marsh habitat in the Gulf of Maine. The highest fish densities from this study (range 0.05 - 0.67 m^{-2}) just overlap with lower fish densities reported from more southerly marshes. Overall, fish were distributed similarly among manipulated and reference marshes, and fish distribution did not change with time. Trends in the data suggest that fish utilize elevated (through deposition of dredge material) marshes restored by dug channels to a lesser degree than impounded marshes restored by culverts. It appears that fish will readily visit restored and created marshes in assemblages similar to those found in reference marshes over the short term (one to five years post-restoration), but are subject to the influence of differences in tidal regime, access to marsh habitat, and vegetation density. In the large majority of cases, hydrologic restoration of tidally restricted marshes will improve a much larger area of fish habitat per unit cost than creation of new marsh, and will not be subject to many of the constraints that limit the function of created marshes. The primary consideration in tidal restora-

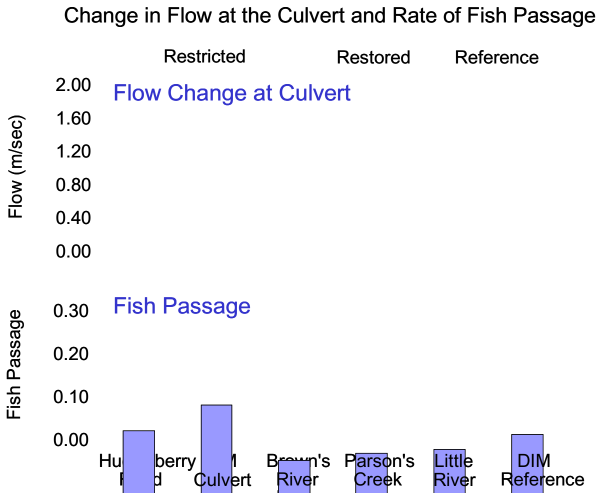


Figure 11-3: Inverse relationship between effect of culvert on water flow (culverts increase flow relative to the wider channel they constrict) and passage of fish through culvert. Reference site shows fish movement and flow change in an unrestricted channel (Eberhardt 2004).

tion projects is not necessarily the cost of construction but the social, economic, and political issues that must be addressed. Often, tidally restricted marshes are located in highly developed coastal areas where many individual property owners may perceive the increased tidal flow as a threat, even when flood hazard studies show that no such threat exists. In spite of this caution, thousands of ha of coastal fish habitat can be improved through a concerted program to restore the hydrology of tidally restricted marshes in the Gulf of Maine.

Dietary Habits of Benthic-feeding Fishes in a Southern Maine Salt Marsh: Evaluation of Prey Availability and Feeding Selectivity (Cartwright 1997)

Spatial and temporal factors affecting daytime benthic invertebrate and fish community structure and trophic patterns were investigated through several experiments in an unvegetated salt marsh creek channel of the Little River in Wells. Abiotic factors such as changes in salinity and seasonal temperature had significant influence on benthic invertebrate community structure. An increase of overall abundance of benthic organisms through the summer was observed, possibly showing a pattern of seasonal succession. Patterns of dominant species varied between upper and lower locations in the estuary.

Spatial and temporal patterns were observed in fish community abundance and diversity. In the lower portion of the estuary, species richness and evenness were the highest, due to the presence of marine species. Fish diets generally mirrored the findings of previous studies. Selectivity analysis of benthic prey revealed that most species exhibited a preference for one or two prey species (Fig. 11-4). This selectivity sometimes switched with prey abundance, which itself showed temporal and spatial variation. Within fish species, the size of the predator did not significantly influence the sizes of the major prey types eaten, but trends suggest that interspecific differences in predator size did play a role in prey size selection. Feeding patterns varied among fish species, with most species broadening their diet when benthic prey became less abundant, concurring with classic optimal foraging theory, while others did not. The dominant prey and niche overlap patterns of fish predators in the Little River estuary contrasted strongly with a previously studied marsh in mid-coast Maine (Lamborghini 1982).

A Comparative Study of the Ecology of Smooth Flounder (Pleuronectes putnami) and Winter Flounder (Pseudopleuronectes americanus) from Great Bay Estuary, New Hampshire (Armstrong 1995)

This study explored the relationship between two closely related species, the smooth flounder and winter flounder. Morphologically and ecologically they are both very similar on a large scale, and co-occur in estuaries from Labrador to Massachusetts. A three-year sampling program's results showed the two species were partially segregated along gradients of salinity and depth in the upper reaches of the Great Bay Estuary. The smooth flounder was most abundant in oligo-mesohaline riverine habitat and the winter flounder in the meso-polyhaline open bay habitat. With the seasonal increase in salinity, both species exhibited a generalized movement up-river. The distribution of smooth flounder along the depth gradient exhibited variation in age class with the smallest juveniles found at the shallowest depths. Intertidal mudflats served as significant nursery area for young-of-the-year smooth flounder but not for young-of-the-year winter flounder. Experiments in the laboratory and field showed that distribution of the two species in Great Bay was largely based on physiological constraints due to salinity. Growth and survival were optimal in particular

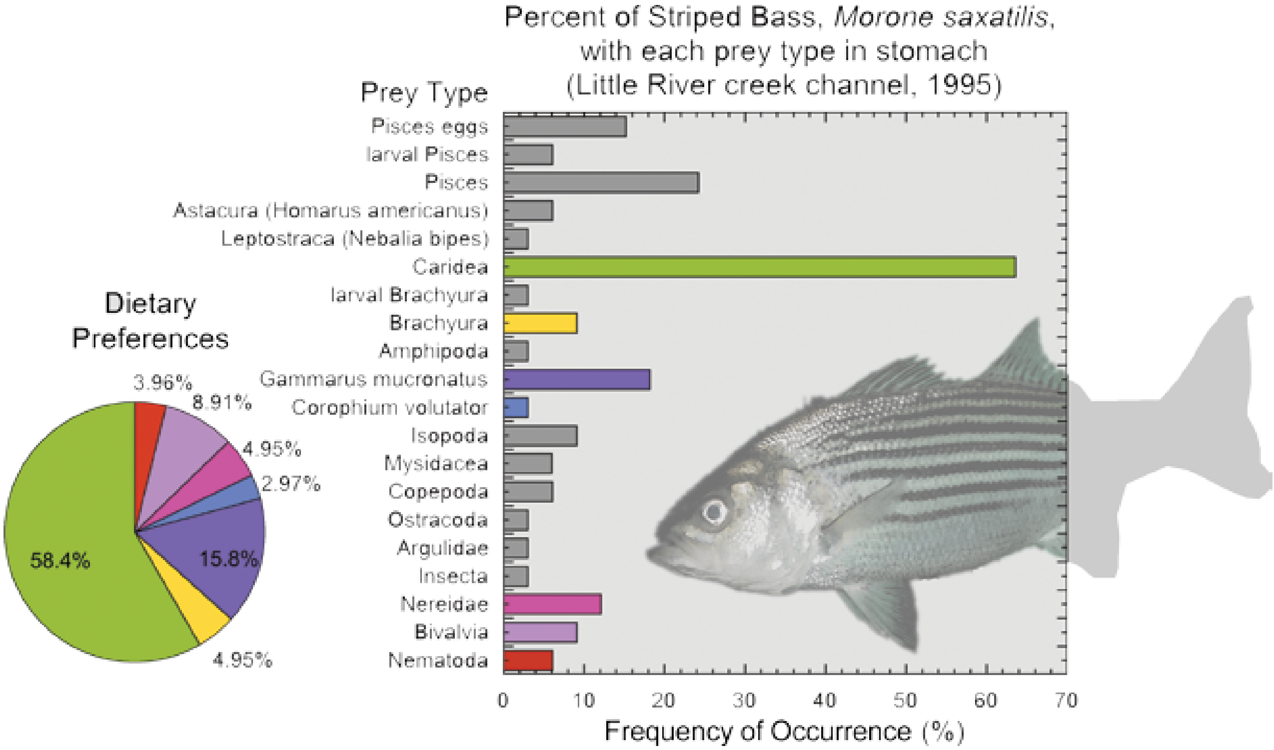


Figure 11-4: Summary and analysis of striped bass (*Morone saxatilis*) stomach contents. Data are pooled from various times in the summer, locations on the Little River, and size classes of bass. The pie chart displays values calculated using Chesson's index, which incorporates prey availability data in order to hypothesize the preferred food choice. See bar graph for species color code. Data from Cartwright 1997. Figure Hannah Wilhel.m

salinities ranges (differing between species), and both species occupied sites along the salinity gradient that corresponded to their specific requirements. Seasonal changes in diet and habitat use were studied at several estuarine sites. Both species exhibited a greater overlap in diet than in habitat use. Their diet was similar and included polychaetes, bivalve siphons, and gammarid amphipods. Seasonal changes in prey abundance seemed to affect distribution of both species. Differences in diet reflected the disparity in benthic organisms at the estuarine sites. No evidence was found to indicate that food was a limiting factor to either species.

A survey of Meiobenthos and Ichthyoplankton in Two Contrasting Estuaries at the Wells National Estuarine Research Reserve (Wells NERR 1994)

The inlets of the Webhannet and Little Rivers lie 1.6 miles apart along the shore of the Wells Embayment. To investigate larval fish communities and linkages between the two estuaries and the bay, ichthyoplankton was sampled on 21 dates over an annual cycle (June 1992 – July 1993). Larvae of 17 fish species were collected, several of which were of recreational or commercial importance: Atlantic herring, Atlantic mackerel, lumpfsh, windowpane flounder, winter flounder, rainbow smelt, and Atlantic tomcod. Larvae of the sand lance, an important forage species, both for piscivorous fish and whales, were also present. Another group of species represented inhabitants of benthic rocky substrates present in the Wells Embayment: cottids (fourbeard rockling, grubby sculpin, longhorn sculpin), northern pipefish, and blennies (radiated shanny, rock gunnel, seasnail, and snake blenny). Fifteen of these species were present in Wells Embayment, 14 in the Webhannet River, and 4 in the Little River (sand lance, rainbow smelt, sea snail, and fourbeard rockling). Mean annual larval fish abundance in Wells Embayment was 1 m^{-3}, tenfold greater than fish abundance in the Webhannet River; Webhannet fish abundance was sixfold greater than Little River fish abundance. Greatest larval fish abundances were observed in late March and early April, with peak abundance in the Embayment at 14 m^{-3}, due to high numbers of sand lance. Temporal variation in fish abundance for the Webhannet reflected that for the Embayment, while the Little River showed no variation for most of the year (e.g. no larval fish present), with one peak in July 1992, coincident with a peak in Wells Embayment. The striking differences in larval fish fauna of the two estuaries invites further monitoring coupled with circulation modelling, to investigate biotic linkages between the Reserve's estuaries and the Gulf of Maine.

Comparison of Habitat Use by Estuarine Fish Assemblages in the Acadian and Virginian Zoogeographic Province (Ayvazian et al. 1992)

Species composition and habitat use of juvenile fishes was compared between the Webhannet estuary (toward the southern end of the Acadian biogeographic province) and Waquoit Bay (also a National Estuarine Research Reserve), at the northern limit of the Virginian province (Cowardin 1979). These sites bracket the biogeographic boundary of Cape Cod. Using seines for samples adjacent to marsh, and trawls for open water, 24 species of fish from fifteen families were sampled from the Webhannet; 48 species and 28 families were found at Waquoit. In the Webhannet, 90 % of the population was composed of four species (ninespine stickleback, sand lance, mummichog and Atlantic silversides). At Waquoit, six species composed 90% of the population (mummichog, fourspine stickleback, tidewater silversides, rainwater killifish, and striped killifish). Adventitious southern and tropical species made up 6% of the catch at Waquoit, while none were present in the Webhannet. Density of fish was greatest adjacent to marsh for both sites, ranging from 65 – 361 • 100 m^{-2} in the Webhannet, and 15 fold higher at Waquoit, due in part to extremely high catches of mummichogs and Atlantic silversides that had shoaled in the marsh for protection on a single winter sampling date. As for fish life histories, 42% of the Webhannet fish individuals were residents, 21% were nursery species, 17% were migratory, and 17% were marine transients. At Waquoit, 33% of fish were residents, 23% were nursery, another 23% were marine transients, with migratory, adventitious and freshwater species comprising the final 20%. The differences between the sites are consistent with larger regional patterns of fish distribution and abundance between the Acadian and Virginian biogeographic provinces, supporting the presence of a biogeographic boundary at Cape Cod.

The Ecology of Estuarine Fishes in Southern Maine High Salt Marshes Access Corridors and Movement Patterns (Murphy 1991)

The purpose of this study was to characterize the ecology of fishes utilizing the high marsh of the Webhannet and Little River estuaries in the summer. Ten of eleven species collected during the study used the intertidal creek for the major point of access to the high marsh. The common mummichog *Fundulus heteroclitus*, which made up the majority of the catch in numbers and biomass, used the marsh edge of the river channel as often as the creek in the Webhannet, while preference was given to the creek in the Little River. The movement patterns of mummichogs between salt marsh pools were investigated using a mark-recapture technique. Only 4% of the fish were recaptured in new locations. This suggests the existence of some type of fidelity to home pools, in these two estuaries.

Seasonal Abundance, Temporal Variation and Food Habits of Fishes in a Maine Salt Marsh Creek System (Lamborghini 1982)

Seasonal occurrences, abundance, patterns of activity and food habits of fishes were investigated in a mid-coast salt marsh creek. Twenty-one species total were collected with spring and summer showing the greatest number of species, and late summer showing the highest number of individuals (Fig. 11-5). Specimens smaller than 150 mm total length comprised the majority of the catch and were adults or juveniles of inshore fishes, and juveniles of larger marine fishes. Dominant species changed with the seasons.

The fishes could be divided into four groups: residents, nursery species, diadromous species, and sporadic visitors. This division was based upon seasonal abundance, length frequencies, stomach contents and occurrence on tide movement. Resident species, which peaked in fall, formed the numeric majority. The number of sporadic visitors peaked in spring. Nursery species were found nearly year round, but especially during summer. Diadromous species were observed primarily in summer. Adult residents were observed to move into the marsh in spring whereas young-of-the-year appeared to exit the marsh in summer and fall. Resident species were collected both day and night, while non-residents were

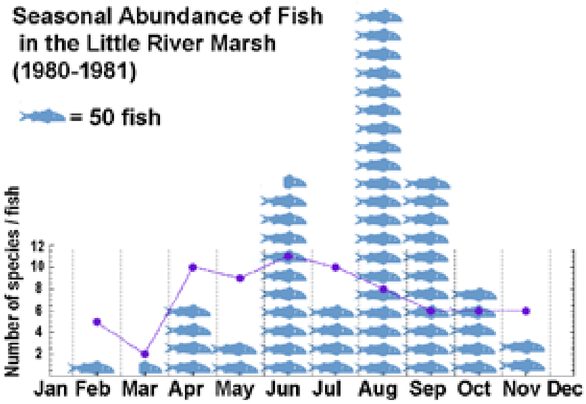


Figure 11-5: Seasonal abundace of fish in the Little River marsh by species (line) and total number of individuals (fish shapes). Data from Lamborghini 1982. Figure Hannah Wilhelm.

found in much greater numbers, or exclusively, at night. Twelve of the twenty-one species were studied for food habits revealing that they were all carnivorous, feeding heavily upon crustaceans. They could be divided into three foraging groups: zooplanktivores, benthic carnivores and mid-water predators. The marsh creek system provided nursery area for resident, diadromous, and marine species.

Summer Distributions of Demersal Finfish in the Montsweag Brook Estuary, Maine (Yoder 1973)

This study was carried out to determine distribution of finfish species as affected by temperature, salinity, and to determine the general summer demersal (i.e., bottom water) fish distributions within the estuary. The estuary is part of the Montsweag Bay-Back River area, which is home to a nuclear-powered generating station (now dismantled). Concerns arose over the impact of thermal effluent on the estuarine environment. Sampling occurred for two consecutive summers. Nine demersal species were collected with six of the nine species having compromised nearly the entire catch. Either an especially rainy summer or artificial warming of adjacent bay waters, or both, contributed to elevated water temperatures in the later summer. This summer of warmer water coincided with a modified distribution of the six major demersal species. The alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) seemed to have benefited (numbers increased from previous year) whereas Atlantic tomcod (*Microgadus tomcod*), smooth flounder (*Pleuronectes putnami*), winter flounder (*Pseudopleuronectes americanus*) and white hake (*Urophycis tenuis*) were adversely affected by the increase in water temperature (numbers decreased from previous year).

The Pelagic and Demersal Finfish of the Montsweag Brook Estuary (Yoder 1972)

Through a variety of sampling techniques, this study was conducted to survey pelagic and demersal fishes in the Montsweag Brook estuary. The estuary is part of the Montsweag Bay-Back River area, which is home to a nuclear-powered electricity plant. Concerns arose over the impact of thermal effluent on the estuarine environment. The four most abundant pelagic fishes were firstly the alewife (*Alosa pseudoharengus*), secondly the Atlantic menhaden (*Brevoortia tyrannus*), thirdly the rainbow smelt (*Osmerus mordax*), and lastly the blueback herring (*Alosa aestivalis*). The four most abundant demersal species were the Atlantic tomcod (*Microgadus tomcod*), the smooth flounder (*Pleuronectes putnami*), the winter flounder (*Pseudopleuronectes americanus*), and the white hake (*Urophycis tenuis*). The low numbers or absence of certain species may have been due to the timing of sampling or the rarity of the species in the area.

Feeding Chronology and Food Habits of the Tomcod (Microgadus tomcod) and Winter Flounder (Pseudopleuronectes americanus) in Montsweag Bay (Sheepscot River) (Alexander 1971)

This study investigated the effects of tide and length of daylight on the chronology of feeding behavior and food habits of tomcod and winter flounder in Montsweag Bay, Maine. Daylight hour sampling occurred three times a day (morning, midday, and evening) at 2-3 day intervals over nearly one-half of the lunar month for consistent sampling of each stage of tide at each time of day. Sampling occurred in the second half of July. Approximately 30 fish were collected per sample and an index of stomach fullness was used to measure variation in feeding intensity. Effects from tide, or photoperiod-tide interaction, were not observed in either species. Tomcod exhibited a peak of feeding activity, or period of intensive feeding, in the early morning with little activity for the rest of the day. Tomcod fed mostly on crustaceans (e.g. sand shrimp, *Crangon septemspinosus*) followed by polychaete worms (e.g. sand worm, *Neanthes virens*). Winter flounder showed feeding activity throughout the day with no definite peaks and fed primarily on polychaetes, followed by mollusks and crustaceans, largely consistent with other food habit studies for this species.

SPECIES ACCOUNTS[1]

To complement the data summarized above from studies of fish ecology in the estuaries of Wells NERR and other Gulf of Maine marsh-estuarine ecosystems, we provide brief accounts for a selection of species. Species were chosen to represent different life histories (resident, migratory, marine transient), importance (economic, forage) or notability. Fishes were sampled using a variety of methods, including a weir (pictured).

Alewife

The **alewife,** *Alosa pseudoharengus* (Fig. 11-6), is an anadromous herring species that can be found in many coastal rivers of the Gulf of Maine. Their average size is 10" – 11" (25 – 28 cm), but they can grow up to 15" (38 cm) long. Most alewives weigh 8 – 9 ounces (230 – 255 g). Alewives use a full range of habitats from fresh water to the edge of the continental shelf. They spend most of their lives at sea and travel back to fresh water to spawn in ponds and slow moving streams. Spawning occurs from late April and early May through June in the Gulf of Maine. Females deposit from 60,000 to 100,000 eggs or more, which cling to twigs, rocks, or detritus. After alewives hatch and grow for a month in fresh water, they successively move downstream in schools numbering in the thousands throughout the summer, making the journey to the ocean by fall. The schools migrating back to freshwater have equally large numbers of fish. Alewives feed on copepods, amphipods, mysids, shrimp, fish eggs, and smaller fish such as eels, sand lance, herring, cunners, and even their own species. After spawning, they depend on the abundant shrimp in estuaries. Eels and perch prey on juvenile alewives, while striped bass and salmon eat spawning adults. Fishermen catch them in weirs in the lower reaches of streams (or in gill nets in outer waters).

The alewife is a species of special historical significance. Early coastal settlers compared them to Atlantic herring and enjoyed an abundance of this fish heading upstream every spring. Native Americans taught the first colonial settlers in New England to plant alewives with crops for fertilizer. Today they are almost exclusively used for lobster bait or processed into pet food and fertilizer.

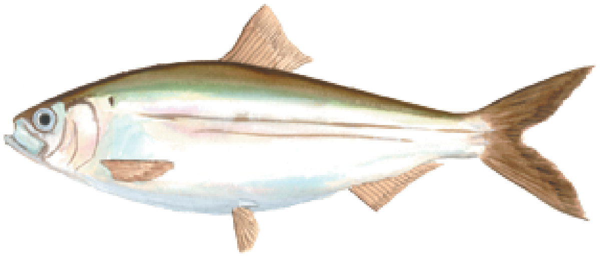


Figure 11-6: Alewife, *Alosa pseudoharengus*. © James Dochtermann.

Alewife populations have fallen in the last few centuries and their range restricted, primarily a result of loss of access to spawning habitat and inadequate streamflow. They are still seen in large numbers in other coastal waterways. Initial restoration efforts have met with success, due to the alewife's resiliency and their ability to quickly discover restored fish passageways.

The alewife is an important forage fish and the only known host for the "Alewife Floater," *Anodonta implicate*, a species of freshwater mussel.

American Eel

The **American eel**, *Anguilla rostrata* (Fig. 11-7, and photo), is a catadromous species found throughout the the Gulf of Maine and its tributaries. Young-of-the-year "elvers" average 2 – 3.5 in (5 – 9 cm), and adult eels can grow to 4 ft (122 cm) long. Some elvers remain in tidal marshes, river mouths or bays behind barrier beaches, while others head into freshwater, ascending large rivers. They are very temperature tolerant. Larger (adult) eels are famous for being found in nearly every aquatic habitat known to have any sort of connection to the ocean, and can over-winter in mud. Eels spawn in midwinter. From December to January, they transform into elvers and head toward inshore waters. The migration ends in the mouths of New England streams and rivers by the following spring. There are four stages in their life cycle: 1) leptocephalus, 2) glass eel, 3) yellow ee, 4) silver eel. Eels live as free-floating larvae ("leptocephali") before they metamorphose into "glass eels" (which can swim) and

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[1] Primary source for this section is Bigelow and Schroeder (1953). Updated information is available in the most recently revised Edition: Collette and Klein-MacPhee (2002).

A weir was used to survey fish use of the Little River on a daily basis. Photo Wells NERR.

head toward the coast. They appear along our shores in the spring and enter estuaries where they become known as "elvers" (pictured). During the following "yellow eel" stage, males generally remain in estuaries for a few years and females venture into freshwater, often long distances, and can remain there for 10 – 30 years before migrating out to spawn. As they reach sexual maturity known as the "silver eel" stage, the eels that are in fresh water head downstream in the fall, traveling mostly at night. They then make the long journey back to their natal waters in the Sargasso Sea (near Bermuda) to deposit their eggs, which float in the upper water layers until hatching. Eels die after spawning, though the final stages of the eel's life cycle are still not well documented.

Eels eat mostly plankton during the larval stage, but as juveniles and adults they become carnivorous and also feed on dead fish and other detritus. They are primarily nocturnal feeders. While in salt or brackish water, they feed on small fishes, crabs, lobsters and other crustaceans. In fresh water, they feed on worms, snails, aquatic insect larvae, crayfish, small fishes, and frogs. They cease feeding when they reach sexual maturity. Many predators eat eel larvae and elvers. Adult eels are eaten by sharks and swordfish in the ocean and are caught by anglers in fresh water.

Elver. Photo James Dochtermann.

The numbers of American eel have been in decline due to over-fishing, pollution and restriction of access to freshwater habitat by dams.

Atlantic Tomcod

The **Atlantic tomcod,** *Microgadus tomcod* (see photo), is a bottom-dwelling member of the cod family. Adults average 9" – 12" (23 – 30 cm) long. They are year-round residents of estuaries, frequently inhabiting salt marsh channels, mouths of streams, and sometimes eel grass beds. Considered an anadromous species, tomcod migrate upriver to spawn in the shallow brackish water of estuaries from November through February, peaking in January. Spawning occurs over gravelly bottoms and sand; eggs sinking to the bottom in masses. Incubation takes 24 – 30 days at temperatures of 30 – 43°F (4 – 6°C). Young-of-the-year may remain in brackish water for the first spring and summer of their lives.

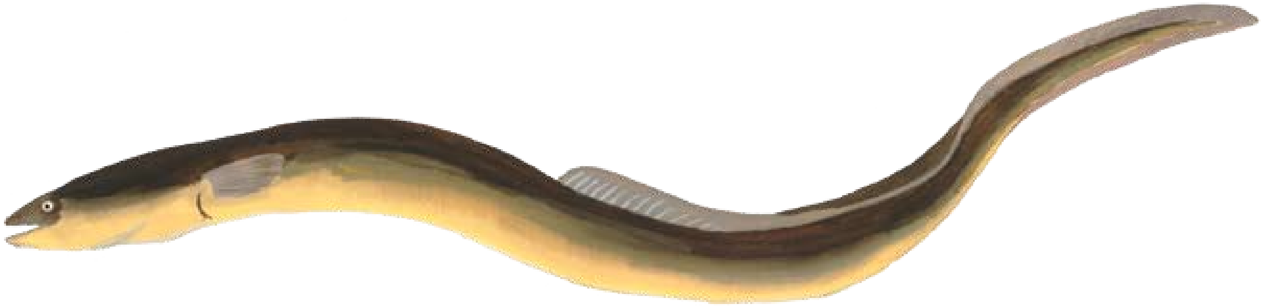


Figure 11-7: American eel, *Anguilla rostrata.* © James Dochtermann

Atlantic silverside sampled from a Casco Bay fringing marsh. Photo Cayce Dalton.

Adults are known to feed on their own eggs, larvae, and juveniles during winter and spring. They also eat small crustaceans, worms, small mollusks, squid, and fish larvae. Larval tomcod eat mostly copepods. At 1 to 2 years old, tomcod primarily eat amphipods and decapods. Yearling striped bass and bluefish prey on tomcod. Tomcod produce antifreeze proteins, which enable them to tolerate water temperatures below freezing. The protein is similar to that found in some arctic and antarctic fishes. They are resistant to sudden changes in temperature and salinity.

The story of the demise of tomcod populations is probably the same as with all anadromous fishes: loss of access to spawning grounds, over-fishing and exposure to pollutants.

Atlantic Silverside

The **Atlantic silverside,** *Menidia menidia* (Fig. 11-8, and see photo), are an abundant, pelagic, year-round resident in coastal shores, bays, river mouths, salt marshes, and brackish waters. Adults average 4.5 in (11.4 cm) long. Young fish are found in estuaries in a range of intertidal and subtidal habitats, and in deeper near-shore waters with sandy bottoms, shell beds, eel grass and sea lettuce. Spawning occurs from May though early July in southern New England, possibly later in the Gulf of Maine. Atlantic silversides gather in schools to spawn, and lay eggs on sandy bottoms or in marsh grasses at high tide. The eggs quickly sink and stick to the substrate in ropy clusters or sheets.

The Atlantic silverside is omnivorous; feeding on copepods, amphipods, mysids, shrimps, juvenile squid, mollusk larvae, small marine worms, fish eggs, fallen insects, algae and diatoms. They are a forage fish for striped bass, bluefish and mackerel, and prey for sea birds.

Mummichog

The **mummichog**, *Fundulus heteroclitus* (see photo), is without doubt the most abundant resident marsh-estuarine fish species in the Gulf of Maine. Adults average 3 .5 in – 4 in (9 – 10 cm) long. They are found in sheltered

Atlantic Tomcod. Photo James Dochtermann.

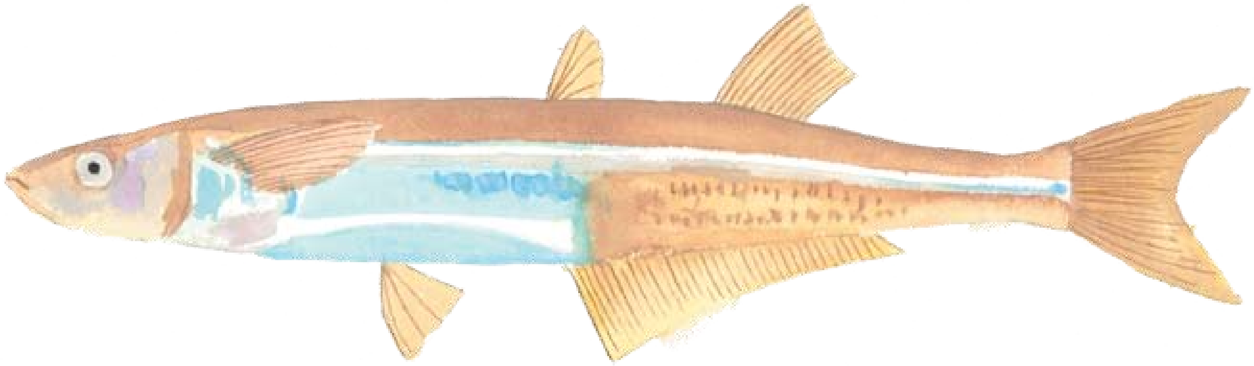


Figure 11-8: Atlantic silverside, *Menidia menidia*. © James Dochtermann

shores among eelgrass and salt hay flooded by high tides, in salt marsh tidal creeks, and in brackish streams. At ebbing tides, they can become concentrated in marsh pools where they tolerate low dissolved oxygen, high carbon dioxide, high temperatures, and a wide range of salinities. In the winter they move to deeper areas, sometimes burrowing in the mud, but mummichogs are not likely to move out to Gulf waters. Spawning occurs from early spring to summer. Sexual maturity is reached at 1 – 2 years. The males, brilliantly tinted at sexual maturity, court the females and drive off rivals. They spawn in a few inches of water, the male clasping the female behind the anal and dorsal fins with his fins, usually pressing against a stone or the bottom. Their tails vibrate rapidly while the eggs and milt are released. The eggs, colorless and surrounded by a firm capsule, sink and clump together or stick to anything they fall upon. Incubation lasts 9 to 18 days and the larvae are about .25 in (7 mm) long at hatching. Many young-of-the-year remain in marsh pools during the first summer.

Mummichogs are omnivorous, eating mostly eelgrass and other vegetable matter, as well as shrimp and other tiny crustaceans, mollusks, and insect larvae. They will also gather around and feed on dead fish. During spawning they sometimes eat their own or each other's eggs. Mummichogs are eaten by surface-feeding birds such as egrets, common terns, herons and king fishers; mammals, and large predatory fish such as striped bass and brook trout.

Fourspine Stickleback

The **fourspine stickleback,** *Apeltes quadracus* (Fig. 11-9, and photo), is a year-round resident commonly found among mummichogs and other sticklebacks in estuaries. Similar to the threespine, they move into fresh water but are known to be more of a brackish and salt water fish; they never move very far inland or offshore. Adults average 1.5 in – 2.5 in (3.8 – 6.3 cm) long. Spawning occurs from late May through early July. Males build nests in intertidal areas with aquatic vegetation. When females enter their territory, the males prod them and then swim to the nest. Females eventually enter the nest site and deposit their eggs. Larvae are about 4.5 mm long. Fourspine live for about one year, but some may reach two.

Fourspine sticklebacks are omnivorous with a diet mainly consisting of copepods and other small crustaceans. They are eaten by the American eel, tomcod, killifish, and other sticklebacks, including their same species; and birds such as common terns, kingfishers, and egrets.

Mummichogs. Photo James Dochtermann.

Fourspine stickleback. Photo James Dochtermann.

Ninespine Stickleback

The **ninespine stickleback**, *Pungitius pungitius* (Fig. 11-10, and photo), is a benthopelagic species (living and feeding near the bottom, and in the water column) found in freshwater, brackish, and marine habitats. Adults average 2 – 2.5 in (5.1 – 6.3 cm). They commonly share shallow estuaries and tidal marsh pools with the threespine stickleback, preferring areas of dense weed cover. Freshwater populations prefer shallow, vegetated parts of ponds, lakes, and pools or slow streams; and sometimes occur over sand. Marine populations are found near shore and might exhibit a seasonal migration, offshore in the fall to deeper water, and inshore in the spring to spawn. They are the most abundant of the four stickleback species occurring at the Wells NERR.

Spawning occurs from spring to summer. Considered by some to be anadromous, they spawn upriver in freshwater regions, but sometimes just above the head of tide or in brackish water. Males build a nest, attached to grasses or weeds where the females spawn, and guard the nest until eggs hatch in 5 – 12 days. Eggs are semi-buoyant, and a relatively turbulent current may be needed in order to prevent the eggs from settling and being silted over. They live one to two years.

Ninespine sticklebacks eat mostly small crustaceans and aquatic insects; also eggs and larvae of their own species during spawning season, and eggs and young of other fish. Tomcod, Atlantic cod, silver hake, and larger striped bass may prey on juveniles. Adults seem to have fewer predators though are eaten by common terns, kingfishers, and egrets.

Rainbow Smelt

The **rainbow smelt**, *Osmerus mordax* (Fig. 11-11), is a pelagic species found in freshwater, brackish and marine habitats with a depth range to 150 m. Adults average 7 – 9 in (18 cm – 23 cm) long, weighing 1 – 6 ounces (28 – 170 g). As an inshore fish, many reside in estuaries when not spawning. Antifreeze activity has been detected in their blood, enabling them to spend winters near shore in freezing temperatures. Spawning occurs from early March through April. The rainbow smelt is anad-

Ninespine stickleback. Photo James Dochtermann.

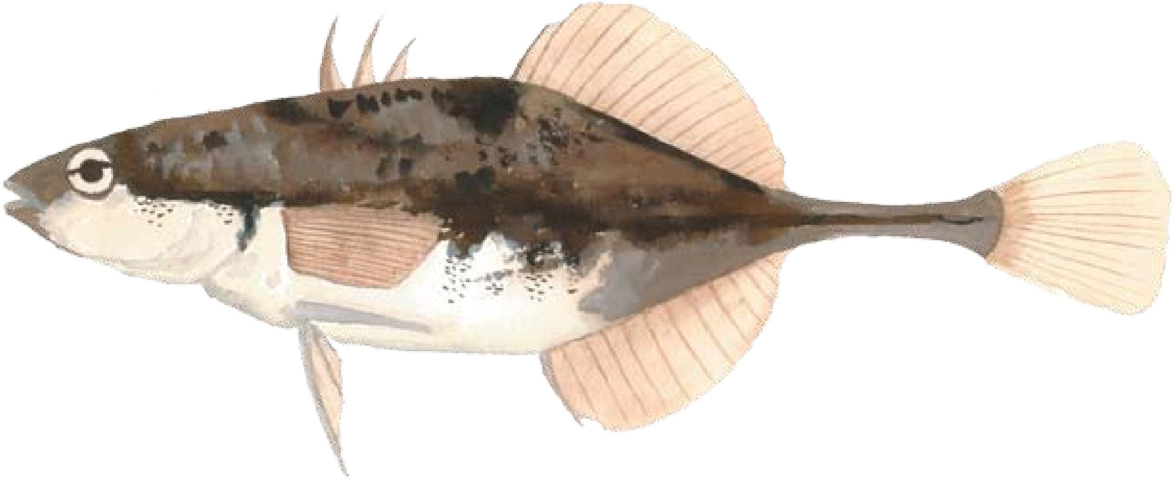


Figure 11-9: Fourspine stickleback, *Apeltes quadracus*. © James Dochtermann

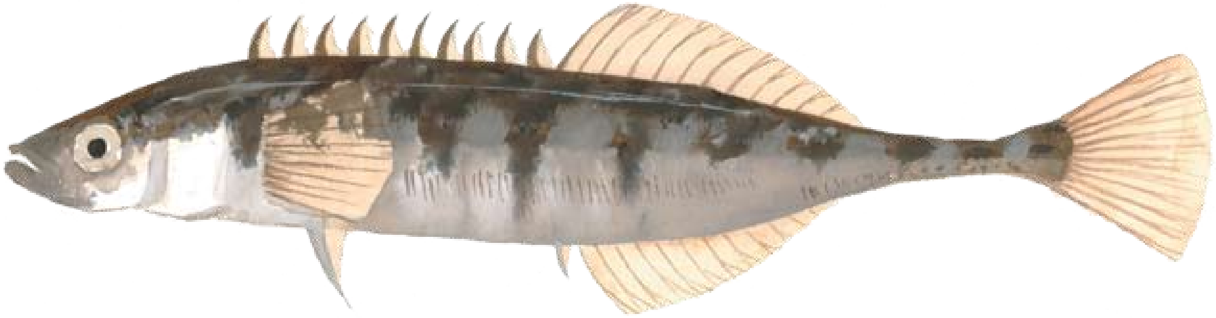


Figure 11-10: Ninespine stickleback, *Pungitius pungitius.* © James Dochtermann

romous, beginning spawning migration in early March once ice melts and the water temperature rises to 40°F (5°C). They spawn in fresh water brooks and streams, or in slightly brackish water below head of tide, but generally do not journey far upstream. Eggs are very small and adhesive, sticking to gravel, rocks, plants, sticks, and other eggs. Adult smelt return to salt water immediately after spawning to spend the summer either in the estuary or out at sea.

Both adults and juveniles are schooling fish and voracious predators. Adults feed mostly on small crustaceans, such as shrimp and mysids, and small fish such as sticklebacks, alewives, and silversides. Marine worms, shellfish, crabs, and squid have been found in their stomachs. They fast during spawning runs to fresh water. Juvenile smelt depend on copepods and other small pelagic crustaceans. An important forage fish, smelts are eaten by their own species and larger fish. They are also eaten by seals and by birds such as mergansers, cormorants, terns, and gulls.

The rainbow smelt recreational fishery is regulated by the Maine Department of Marine Resources. When they swim to natal streams to spawn in the spring, fishermen use dip nets to catch them. In winter, anglers fish for smelt through the ice on Maine's tidal rivers and saltwater bays. They are a regional seasonal delicacy. They once supported a large commercial fishery in the Gulf of Maine. Over the last 50 years, however, their streams have been obstructed or polluted, leading to the demise of this important local fishery.

Sand Lance

The **sand lance**, *Ammodytes americanus* (Fig. 11-12, and photo), is a pelagic, marine species found at river mouths, harbors, and estuaries, but also over offshore banks. Adults are 4 to 6 in (10–15 cm) long. Sand lance divide time between the water column and bottoms of fine gravel or sand, avoiding substrates of silt or mud. They bury themselves during periods of low light, during dormant periods, and sometimes in response to predators. They tolerate a range of temperatures and salinities. Spawning occurs from December to February. Sand lance often

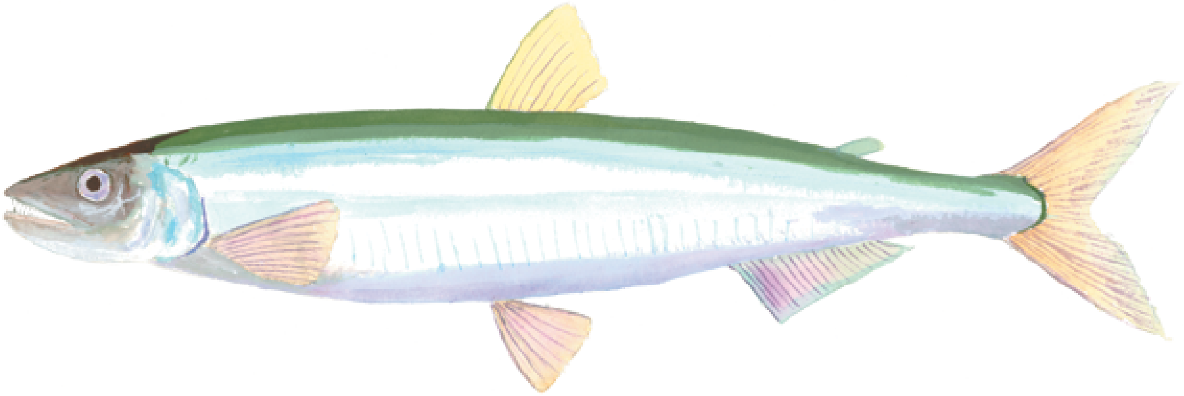
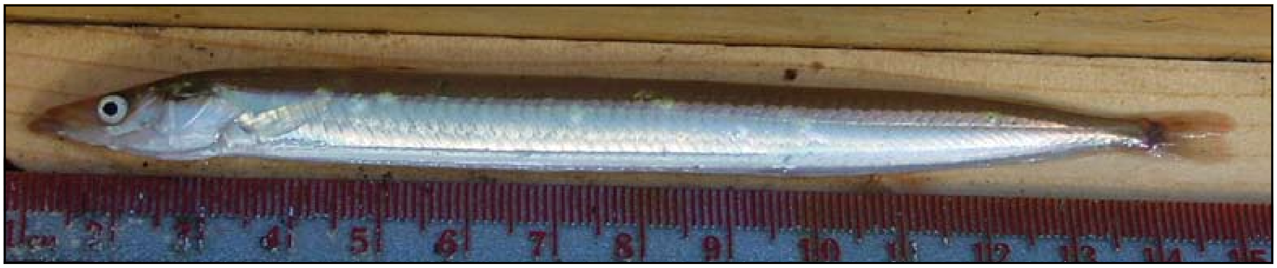


Figure 11-11: Rainbow smelt, *Osmerus mordax.* © James Dochtermann



Sand lance. Photo James Dochtermann.

form large, dense schools, sometimes with herring. They may become inactive or hibernate while buried in winter. Sand lance mature in 2 years. Females spawn *en masse* once a year. Their adhesive eggs remain on the bottom, sticking to grains of sand. Incubation period varies with temperature and oxygen level, and may range from 2 to 9 weeks. Sand lance can live several years.

Adult sand lance prey upon copepods, chaetognaths (arrow worms), larval fish, and a variety of other animals. Small larvae eat phytoplankton, diatoms, and dinoflagellates, then graduate to copepod larvae and euphausiids (type of krill). Sand lance feed during the day, perhaps especially in morning and evening. The sand lance is an important forage species (perhaps critically important) for seabirds, fishes such as cod and yellowtail flounder, and marine mammals including the North American right whale.

Winter Flounder

The **winter flounder**, *Pseudopleuronectes americanus*, is a demersal (bottom-dwelling) flatfish that lives in marine habitats preferring substrates of sand, silt, or mud. Generally adults are from 12 - 15 in (30.5 - 38 cm) in length and 1.5 - 2 lbs (680 - 907 g) in weight. It can be found moving up to brackish water of river mouths and estuaries, salt marshes, bays, and in nearshore and offshore waters. The range of water temperature tolerance for adults appears to be from around 30 - 66°F (-1.1 - 18.8 °C). Its distribution is spread across a wide spectrum of temperatures at each season, from the near freezing point of saltwater (in Canadian waters—and which can occur in shallower parts of the Gulf of Maine in late winter), to 64°-66°F (17.7°-18.8°C; in the southwestern part of the Gulf of Maine in summer) to possibly 70°F (21.1°C) in the southern part of its range.

Spawning occurs from January to May. Most winter flounder reach maturity after about 2.5 - 3.5 months. They spawn on sandy substrate often in nearshore waters as shallow as 1 to 3 fathoms (1 fathom = 6 feet or 1.83 meters), but also in deeper offshore waters as deep as 25 to 40 fathoms on George Bank. Spawning occurs when water temperatures reach the coldest range of the year, about 31°-35°F. In the inner parts of the Gulf of Maine, most eggs are produced in water with salinity from about 31 – 32.3 mg L^{-1}. Some are known to spawn in estuaries but do so in brackish water with salinity around 11 mg L^{-1}. Egg incubation lasts 15 – 18 days at a water temperature of 37°-38°F. Winter flounder larvae are common near the mouths of estuaries. They are pelagic to 8 – 9 mm long, by which time the right eye has migrated and the small fish settle on the bottom, roughly six weeks after hatching. Winter flounder (see photo) use marsh-estuarine habitat as nurseries during their first growing season in the Gulf of Maine.

The adult winter flounder's small mouth limits what it can eat to small invertebrates and fish fry. Common invertebrates that are included in the winter flounder's

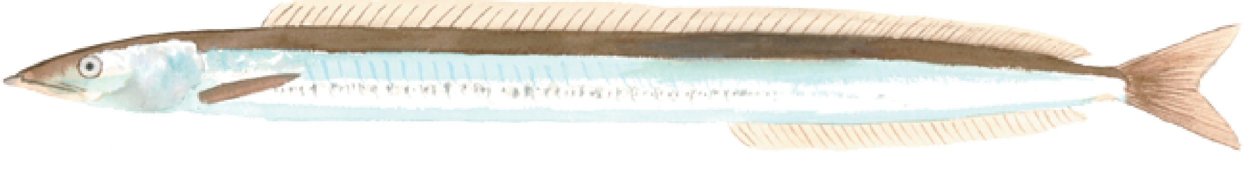


Figure 11-12: Sand Lance, *Ammodytes americanus*. © James Dochtermann

Winter flounders from a salt marsh creek, York River. Photo James Dochtermann.

diet include shrimp, amphipods, small crabs, or other crustaceans; sometimes ascidians, sea worms (*Neanthes* spp.), or other annelids; and bivalve or univalve mollusks. Cormorants and large heron prey on winter flounder; common terns feed on juveniles. The flounders are the flat chameleons of the estuaries and sea, able to change color to blend in with the bottom and await the arrival of prey, and hide from predators.

The winter flounder fishery is managed under the New England Fishery Management Council's Multi-species Fisheries Management Plan (FMP); and is the most highly sought-after flatfish by recreational anglers. Flounder fishing is a popular activity from boats, piers, and bridges along the Gulf of Maine's tidal rivers, estuaries, bays, and harbors. Many anglers attest that the flounder have "disappeared," or numbers have drastically declined, from coastal waters throughout New England.

Northern Pipefish

The **northern pipefish**, *Syngnathus fuscus* (Fig. 11-13, and photo), can be found in marine or brackish waters, among eelgrass or seaweed in shallow bays, salt marshes, harbors, creeks, and river mouths. Pipefish are often found under floating rockweed along the Maine coast. They can tolerate a salinity range of 0 – 38.8 PSU, and temperature range of 37°–95°F (3°–35°C). Adults are rarely longer than 8 in (20.8 cm). They are commonly found in the intertidal zones of estuaries. It is believed that the pipefish migrate inshore-offshore seasonally, moving from estuaries in the spring and fall, to near-shore continental shelf waters in September and October. Spawning occurs from March to October. Males carry the eggs, with a brood pouch capacity of 104 – 570 eggs. The female inserts her protruding oviduct into the opening of the male's pouch to transfer one dozen or more eggs at a time, in succession, until the pouch is filled. It is believed that fertilization takes place during the transfer of eggs. Larger males hold two to four rows in two or three layers on each side of the pouch. Incubation takes about 10 days. The young remain in the pouch until they are 8–12 mm long, and are ready to leave the pouch and live independently. Sexual maturity is reached around one year.

The pipefish are diurnal (daytime) feeders, eating mostly copepods, amphipods, fish eggs, and very small fish larvae, polychaete worms, and mysid shrimp. They are eaten throughout their range by fishes, including the smooth dogfish (*Mustelus canis*), cod (*Gadus morhua*), sea raven (*Hemitripterus americanus*), black sea bass (*Centropristis striata*), weakfish (*Cynoscion regalis*), oyster toadfish (*Opsanus tau*), and bluefish (*Pomatomus saltatrix*).

Striped Bass

The **striped bass**, *Morone saxatilis* (see photo), is a demersal species found in freshwater, brackish, and marine habitats. With the exception of breeding season, striped bass are usually found along the coastline in bays, small marsh estuaries, in river mouths, and off the open coast; younger ones tend to school. The majority of large bass (30 lbs or 13.6 kg or larger) are found on the open

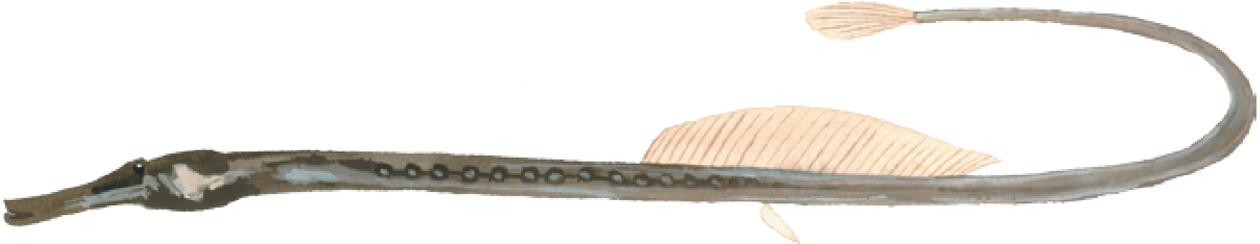
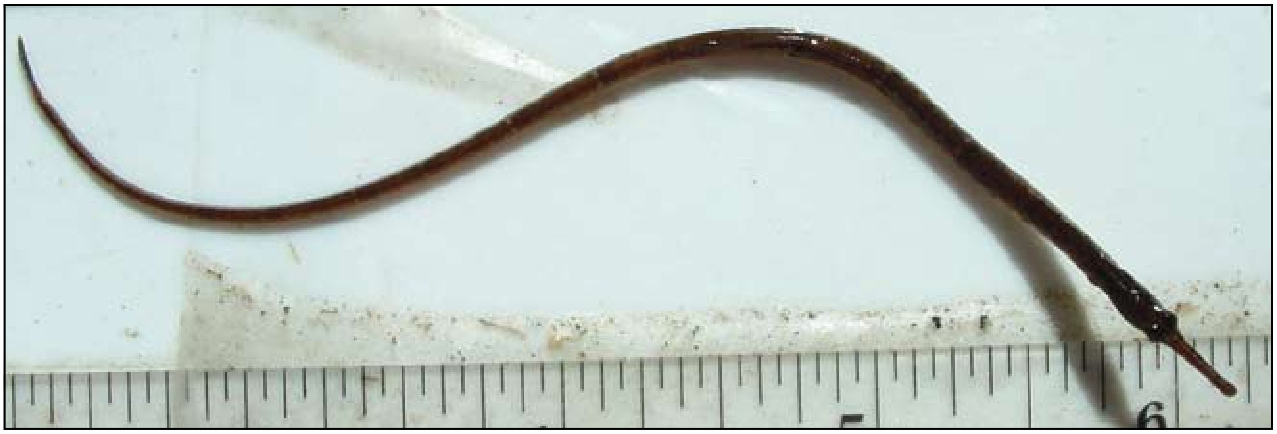


Figure 11-13: Northern Pipefish, *Syngnathus fuscus.* © James Dochtermann.



Northern Pipefish, Little River at Wells NERR. Photo James Dochtermann.

coast along sandy beaches, among rocks and boulders, and at estuary mouths. Striped bass are known to school, moving along the coast within the same general environs during the summer. They are active until the temperature falls below 43°F (6°C) when they leave for warmer offshore waters or loll at the bottom of an estuary in a dormant state. Adults weigh from 3 – 35 lb (1.4 – 15.9 kg). A 20 lb (9 kg) bass averages 36 in (91.4 cm) long. Females grow larger than males.

The striped bass is an anadromous species, migrating to spawn in brackish water at the mouth of estuaries or upriver in fresh water. Spawning occurs from May to July. The water must be turbulent enough so the eggs will not settle on the bottom where they could be smothered. Females can deposit from ten thousand to one million semi-buoyant eggs that tend to drift downstream with the current. Eggs hatch in 4 to 10 days in water temperatures of 58°–60°F (14°–16°C). Larvae form small schools and move inshore. Juveniles move down river into waters of higher salinity during their first summer. Females mature at 4 to 5 years and males mature at 2 to 3 years.

The striped bass is a carnivorous species that feeds on smaller fish and a variety of invertebrates, including herring, smelt, sand lance, eels, silver hake, squid, crabs, lobsters, and sea worms. In the 1970's and 1980's there was a significant decline in recreational and commercial landings of striped bass, attributed to over-fishing and poor water quality in spawning habitats. Striped bass are managed under the Atlantic States Marine Fisheries Commission. In 1995, Atlantic striped bass were declared a restored stock and restrictions were somewhat relaxed. Due to this resurgence in numbers, "Stripers" persist as

A young Striped Bass or "schoolie," Little River, Wells NERR. Photo James Dochtermann.

one of, if not the, most sought-after coastal fishes in the Gulf of Maine for recreational angling, whether by lures, bait or flies.

HUMAN INFLUENCES

The offshore commercial ground fisheries in the Gulf of Maine have been in decline for decades (Mayo and Terciero 2005), attributed to a combination of over-fishing, habitat alteration by fishing gear, and changes in food web structure due to species and size selective harvest and bycatch. In response to this decline, the National Marine Fisheries Service now incorporates habitat information and ecological processes into its predictive management models (Busch *et al.* 2003). Much less is known about the status of coastal fisheries in Maine, other than to observe that with the exception of Atlantic herring, many finfish species are no longer abundant enough to support viable commercial day fisheries. Beginning in 2000, Maine and New Hampshire began a collaborative inshore trawl survey to assess the status of coastal finfish populations. Prior to that time, concerns about the fixed-gear fishery (e.g. lobster) prevented fisheries-independent research trawling in coastal waters. With four years of spring and fall surveys completed, enough data are available to begin stock assessments (Sherman *et al.* 2005). The coastal lobster fishery, in contrast, has continued to grow, apparently subsidized by the great biomass of finfish bait that is consumed by lobsters that escape from baited traps (Grabowski *et al.* 2005). The structure of the coastal food web has been clearly modified through human action, but little is known about the causes and consequences of this change, or of the interaction between coastal and offshore food webs. In marsh-dominated estuaries, the most obvious human influences involve alterations of hydrology through increased runoff from shoreland development, tidal restrictions created by roadways and culverts, and inlet dredging.

RESEARCH NEEDS

Although we know more about marsh-estuarine fish communities in the Gulf of Maine than was known a decade ago, we still lack an understanding of the role of marsh-estuarine ecosystems in supporting coastal food webs and Gulf of Maine fish populations. We suggest the following broad lines of research to improve our understanding. These topics apply equally well to back-barrier and fringing marsh habitats.

- ◊ Investigate linkages between larval, juvenile and adult fish species in marsh-estuarine ecosystems and Gulf of Maine nearshore waters.
- ◊ Investigate importance of marsh resident fish species as forage for marine transients.
- ◊ Investigate food web transfer of energy from marsh-estuarine primary producers.
- ◊ Investigate role of the non-native green crab in marsh-estuarine food webs.
- ◊ Investigate relationship between fish community structure / diversity and salt marsh hydrology, geomorphology and geography.
- ◊ Investigate ecosystem level functions related to marsh-estuarine fish community structure and biodiversity.

MANAGEMENT RECOMMENDATIONS

Although vegetated salt marsh is now reasonably well protected against drastic insults such as large-scale dredging and filling, this type of impact continues on the small scale (e.g. docks, roadwork, bulkheads). Surprisingly, there is no assessment of the cumulative loss of salt marsh habitat and associated ecological functions (Dionne *et al.* 1998). To properly assess these losses, fringing marsh habitat would need to be mapped statewide. In addition, increasingly intense development in adjacent upland is rapidly reducing the ability of shoreland buffers to protect salt marshes from stormwater, and the nutrients and contaminants it often delivers to salt marshes and other intertidal habitats. Finally, a specific site selection plan is needed to guide the restoration of hydrologically altered marshes in Maine. We recommend that relevant state agencies (State Planning Office, Department of Environmental Protection, Department of Marine Resources, Department of Transportation) initiate collaborative programs to improve the protection and restoration of coastal marshes from these pressing human influences.

References

Alexander, L.C. 1971. Feeding chronology and food habits of the tomcod (*Microgadus tomcod*) in Montsweag Bay (Sheepscot River). Masters Thesis. University of Maine, Orono, ME. 36 pp.

Armstrong, M.P. 1995. A comparative study of the ecology of smooth flounder (*Pleuronectes putnami*) and winter flounder (*Pseudopleuronectes americanus*) from Great Bay estuary, New Hampshire. Dissertation. University of New Hampshire, Durham, NH. 147 pp.

Ayvazian, S.G., L.A. Deegan and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. Estuaries 15: 368-383.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. United States Fish and Wildlife Service Fishery Bulletin 74. Washington, DC. 577 pp.

Boesch, D.F. and R.E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries: 7(4A): 460-468.

Bozeman, E.L. and J.M. Dean. 1980. The abundance of estuarine larval fish in a South Carolina intertidal creek. Estuaries. 3: 89-97

Busch, W-D.N., B.L. Brown and G.F. Mayer. 2003. Strategic guidance for implementing an ecosystem-based management approach to fisheries management. NOAA/NMFS Marine Fisheries Advisory Committee, Silver Spring, MD. 57 pp.

Cartwright, M. A. 1997. Dietary habits of benthic-feeding fishes in a Southern Maine salt marsh: evaluation of prey availability and feeding selectivity. Dissertation, University of Maine, Orono, ME. 135 pp.

Chen, C. Y., M. Dionne, R. A. MacKenzie, A. Bilgili and B. Mayes. 2004. Bioaccumulation of metals in intertidal food webs. Abstract Book, pp. 27. American Society of Limnology and Oceanography Ocean Research Conference, Honolulu, Hawaii.

Collette, B.B. and G.Klein-MacPhee, *editors*. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine,Volume 3. Smithsonian Institution Press. Washinton, DC. 748 pp.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. La Roe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Fish and Wildlife Service, Office of Biological Services, Washington, D. C. FWS/OBS-79/31. 131 pp.

Currin C. A., S. C Wainright., K. W. Able, M. P. Weinstein and C. M. Fuller 2003. Determination of food web support and trophic position of the mummichog, *Fundulus heteroclitus*, in New Jersey smooth cordgrass (*Spartina alterniflora*), common reed (*Phragmites australis*), and restored salt marshes. Estuaries 26:495-510

Day, J.W., C.A.S. Hall, W.M. Kemp, A. Yanez-Arancibia. 1989. Nekton, the free swimming consumers. *In* Estuarine ecology. *Edited by* J.W. Day, C.A.S. Hall, W.M. Kemp, A. Yanez-Arancibia. John Wiley, NY, N.Y. pp. 377-437.

Deegan, L.A., B.J. Peterson and R. Portier. 1990. Stable isotopes and cellulase activity as evidence of detritus as a food source for juvenile Gulf menhaden. Estuaries 13: 14-19.

Deegan, L. A. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. Canadian Journal of Fisheries and Aquatic Science 50: 74-79.

Deegan, L.A. and R.H. Garritt. 1997. Evidence for spatial variability in estuarine food webs. Marine Ecology Progress Series 147: 31-47.

Dionne, M., D. Burdick, R. Cook, R. Buchsbaum and S. Fuller. 1998. Scoping paper 5: physical alterations to water and salt marshes. Commission for Environmental Cooperation. Montreal, Canada. 57 pp.

Dionne, M., F. Short and D. Burdick. 1999. Fish utilization of restored, created and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.

Dionne, M., M. Haas and A. Leonard. 2006. Developing an index of tidal wetland health in the Gulf of Maine using fish as indicators. Report to USEPA Office of Ecosystem Protection Small Grantees Program, Boston, MA. 25 pp.

Doering, P.H., C.T. Roman, L.L. Beatty, A.A. Keller and C.A. Oviatt. 1995. Water quality and habitat evaluation of Bass Harbor Marsh-Acadia National Park, Maine. Dept. of the Interior, National Park Service, New England System Support Office. Technical Report NPS/NESORNR/NRTR/95-31. 147 pp.

Eberhardt, A.L. 2004. Fish versus human corridors: the impacts of road culverts on nekton community composition and movement in New England salt marshes. Masters Thesis, University of New Hampshire, Durham NH. 134 pp.

Felley, J.D. 1987. Nekton assemblages of three tributaries to the Calcasieu estuary, Louisiana. Estuaries 10: 321-9.

Grabowski, J., E. Clesceri, A. Baukus, J. Gaudette and P. Yund. 2005. Interactions among herring and lobster fisheries in the Gulf of Maine. Abstract. Ecological Society of America Annual Meeting, Montreal, Quebec, Canada.

Griffin M.P.A. and Valiela, I. 2001. δ^{15}N isotope studies of life history and trophic position of *Fundulus heteroclitus* and *Menidia menidia*. Marine Ecology Progress Series 214: 299-305.

Hayes, P.S. 2005. An estimate of the economic value of southern Maine tidal wetlands to the Maine commercial groundfish industry. Masters Thesis, Antioch New England Graduate School, Keene, NH. 137 pp.

Hettler, William F., Jr. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. Marine Ecology Progress Series 56: 111-118.

Irlandi, E.A. and M.K. Crawford. 1997. Habitat linkages: the effect of intertidal saltmarshes and adjacent subtidal habitats on abundance, movement, and growth of an estuarine fish. Oecologia 110: 222-230.

Jacobson, H.A., G.L. Jacobson Jr. and J. T. Kelley. 1987. Distribution and abundance of tidal marshes along the coast of Maine. Estuaries 10: 126-131.

Kneib, R.T. 1993. Growth and mortality in successive cohorts of fish larvae within an estuarine nursery. Marine Ecology Progress Series 94: 115-127.

Kneib, R.T. 1997. The role of tidal marshes in the ecology of estuarine nekton. Oceanography and Marine Biology: 35: 163-220.

Kneib, R. T. and S. L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series 106: 227-238.

Konisky, R.A., D.M. Burdick, M. Dionne and H.A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology 14(4): 516-525.

Lamborghini, P.L. 1982. Seasonal abundance, temporal variation, and food habits of fishes in a Maine salt marsh creek system. Masters thesis. University of Maine at Orono. 70 pp.

Lazzari, M.A.S. Sherman, C.S. Brown, J. King, B.J. Joule, S.B. Chenoweth and R.W. Langton. 1999. Seasonal and annual variation in abundance and species composition of two nearshore fish communities in Maine. Estuaries 22(3A): 636-647.

Litvin, S.Y. and M.W. Weinstein. 2004. Multivariate analysis of stable-isotope ratios to infer movements and utilization of estuarine organic matter by juvenile weakfish (*Cynoscion regalis*). Canadian Journal of Fisheries and Aquatic Science 61: 1851-1861.

Mayo, R.K. and M. Terceiro, *editors*. 2005. Assessment of 19 Northeast groundfish stocks since 2004. 2005 Groundfish Assessment Review Meeting. Reference document 05-13. Northeast Fisheries Science Center, Woods Hole, MA. 508 pp.

McHugh, J.L. 1967. Estuarine nekton. *In* Estuaries. *Edited by* G.H. Lauff. American Association for the Advancement of Science, Special Publication 83. Washington, D.C.

Miltner, R.J., S.W. Ross and M.H. Posey. 1995. Influence of food and predation on the depth distribution of juvenile spot (*Leiostomus xanthurus*) in tidal nurseries. Canadian Journal of Fisheries and Aquatic Sciences 52: 971-82.

Minello, T.J. and J.W. Webb, Jr. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Marine Ecology Progress Series 151: 165-179.

Morgan, P.A., M. Dionne, R. MacKenzie and L. Curci. 2005a. Ecological functions and values of fringing salt marshes susceptible to oil spills in Casco Bay, Maine. Maine Oil Spill Advisory Committee, Maine Sea Grant, Orono, ME. 67 pp.

Morgan, P.A., L. Curci, C. Dalton and J. Miller. 2005b. Assessing the health of fringing salt marshes along the fore river and its tributaries. Natural Resource Damage Trustees, Maine Department of Environmental Protection, Portland, ME. 45 pp.

Murphy. S.C. 1991. The ecology of estuarine fishes in southern Maine high salt marshes: access corridors and movement patterns. Masters thesis, University of Massachusetts, Amherst, MA. 87 pp.

Neckles, H.A. and M. Dionne, *editors*. 2000. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve, Wells, ME. 28 pp.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum and E. Hutchins. 2002. A monitoring protocol to assess tidal marshes at local and regional scales. Restoration Ecology 10:556-563.

Peterson. G.W. and R.E. Turner. 1994. The value of salt marsh edge vs. interior as a habitat for fish and decapod crustaceans in a Louisiana salt marsh. Estuaries 17(1B): 235-262.

Rogers, S.G., T.E. Targett and S.B. VanZant. 1984. Fish-nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. Transactions of the American Fisheries Society 113: 595-606.

Roman, C.T. 1987. An evaluation of alternatives for estuarine restoration management: the Herring River ecosystem (Cape Cod National Seashore). Center for Coastal and Environmental Studies, National Park Service Cooperative Research Unit. Rutgers - The State University of New Jersey, New Brunswick, NJ. 304 pp.

Rountree, R.A. and K.W. Able. 1992a. Foraging habits, growth, and temporal patterns of salt-marsh creek habitat use by young-of-year summer flounder in New Jersey. Transactions of the American Fisheries Society 121: 765-776.

Rountree, R.A. and K.W. Able. 1992b. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: composition, abundance, and biomass. Estuaries 15: 171-185.

Rountree, R.A. and K.W. Able. 1993. Diel variation in decapod crustacean and fish assemblages in New Jersey polyhaline marsh creeks. Estuarine, Coastal and Shelf Science 37: 181-201.

Rozas, L.P. 1995. Hydroperiod and its influence on nekton use of the salt marsh: a pulsing ecosystem. Estuaries 18: 579-590.

Shenker, J. and J.M. Dean. 1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: abundance, diversity and temporal variation. Estuaries 2: 154-163.

Sherman, S.A., K. Stepanek, J. Sowles, D. E. Grout and R. Tetrault. 2005. Maine – New Hampshire inshore groundfish trawl survey: fall 2003–spring 2004. Maine Department of Marine Resources, West Boothbay Harbor, Maine. 71 pp.

Smith, S.M., J.G. Hoff, S.P. O'Neil and M.P. Weinstein. 1984. Community and trophic organization of nekton utilizing shallow marsh habitats, York River, Virginia. Fishery Bulletin 82: 455-467.

Szedlmayer, S.T. and K.W. Able. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19: 697-709.

Taylor, P.H. 2007. Salt marshes in the Gulf of Maine: Human impacts, habitat restoration, and long-term change analysis. Gulf of Maine Council on the Marine Environment. 48 pp.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nursery areas for fish and shellfish, Cape Fear River, North Carolina. Fishery Bulletin 77: 339-357.

Weinstein, M.P. and D.A. Kreeger, *editors*. 2000. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Boston, MA. 875 pp.

Weinstein, M.P. and M.F. Walters. 1981. Growth, survival and production in young-of-the-year populations of *Leiostomus xanthurus* (Lacepede), residing in tidal creeks. Estuaries 4: 185-197.

Wells National Estuarine Research Reserve. 1994. A survey of meiobenthos and ichthyoplankton in two contrasting estuaries at the Wells National Estuarine Research Reserve, Maine. Draft final data report to National Oceanic and Atmospheric Administration Wells National Estuarine Research Reserve, Wells, ME. 11 pp.

Wozniak, A.S., C.T. Roman, S.C. Wainwright, R.A. McKinney and M. James-Pirri. 2006. Monitoring food web changes in tide-restored salt marshes: a carbon stable isotope approach. Estuaries and Coasts 29(4): 568-578.

Yoder, C. 1972. The pelagic and demersal finfish of the Montsweag Brook estuary. Unpublished report. 91 pp.

Yoder, C. 1973. Summer distributions of demersal finfish in the Montsweag Brook estuary, Maine. Chewonki Foundation. 15 pp.

Table 11-2: Fish found at Wells NERR. Sources: Fish of the Wells National Estuarine Research Reserve (Checklist), 2002, Casco Bay 2002-4, NEC Project 2002-3, NOAA Project 2005-6
* These species have been found in Gulf of Maine nearshore habitats adjacent to Wells NERR estuaries.

Family	Common Name	Scientific Name
Myxinidae (Hagfishes)	Hagfish	*Myxine glutinosa**
Petromyzontidae (Lampreys)	Sea Lamprey	*Petromyzon marinus*
Squalidae (Spiny Dogfishes)	Spiny Dogfish	*Squalus acanthias**
Rajidae (Skates)	Thorny Skate	*Amblyraja radiata**
Anguillidae (Freshwater Eels)	American Eel	*Anguilla rostrata*
Clupeidae (Herrings)	Blueback Herring	*Alosa aestivalis*
	Alewife	*Alosa pseudoharengus*
	American Shad	*Alosa sapidissima*
	Atlantic Menhaden (Pogy)	*Brevoortia tyrannus*
	Atlantic Herring	*Clupea harengus*
Salmonidae (Trouts)	Atlantic Salmon	*Salmo salar*
	Brown Trout	*Salmo trutta*
	Brook Trout	*Salvelinus fontinalis*
Osmeridae (Smelts)	Rainbow Smelt	*Osmerus mordax*
Gadidae (Codfishes)	Atlantic Cod	*Gadus morhua*
	Fourbeard Rockling	*Enchelyopus cimbrius*
	Atlantic Tomcod	*Microgadus tomcod*
	White Hake	*Urophycis tenuis*
	Red Hake	*Urophycis chuss*
	Silver Hake	*Merluccius bilinearis**
	Cusk	*Brosme brosme**
	Pollock	*Pollachius virens*
Cyprinodontidae (Killifishes)	Common Mummichog	*Fundulus heteroclitus*
	Banded Killifish	*Fundulus diaphanus*
	Striped Killifish	*Fundulus majalis*
Atherinidae (Silversides)	Atlantic Silverside	*Menidia menidia*
	Inland Silverside	*Menidia beryllina*
Gasterosteidae (Sticklebacks)	Fourspine Stickleback	*Apeltes quadracus*
	Threespine Stickleback	*Gasterosteus aculeatus*
	Blackspotted Stickleback	*Gasterosteus wheatlandi*
	Ninespine Stickleback	*Pungitius pungitius*
Syngnathidae (Pipefishes)	Northern Pipefish	*Syngnathus fuscus*
Percichthyidae (Perches)	Striped Bass	*Morone saxatilis*
	White Perch	*Morone americana*
Pomatomidae (Bluefishes)	Bluefish	*Pomatomus saltatrix*
Chaetodontidae (Butterflyfishes)	Spotfin Butterflyfish	*Chaetodon ocellatus*
Labridae (Wrasses)	Cunner	*Tautogolabrus adspersus*
Mugilidae (Mullets)	Striped Mullet	*Mugil cephalus*
Sphyraenidae (Barracudas)	Northern Sennet	*Sphyraena borealis*
Stichaeidae (Pricklebacks)	Snake Blenny	*Lumpenus lumpretaeformis*
	Radiated Shanny	*Ulvaria subbifurcata*
Pholidae (Gunnels)	Rock Gunnel	*Pholis gunnellus*
Ammodytidae (Sand Lances)	Sand Lance	*Ammodytes americanus*

Table 11-2 (continued): Fish found at Wells NERR. Sources: Fish of the Wells National Estuarine Research Reserve (Checklist), 2002, Casco Bay 2002-4, NEC Project 2002-3, NOAA Project 2005-6

* These species have been found in Gulf of Maine nearshore habitats adjacent to Wells NERR estuaries.

Family	Common Name	Scientific Name
Scombridae (Mackerels)	Atlantic Mackerel	*Scomber scombrus*
Stromateidae (Butterfishes)	Butterfish	*Peprilus tricanthus*
Cottidae (Sculpins)	Grubby Sculpin	*Myoxocephalus aeneus*
	Longhorn Sculpin	*Myoxocephalus octodecimspinosus*
	Slimy Sculpin	*Cottus cognatus*
Cyclopteridae (Snailfishes)	Lumpfish	*Cyclopterus lumpus*
	Seasnail	*Liparis atlanticus*
Bothidae (Lefteye Flounders)	Windowpane	*Scopthalmus aquosus*
Pleuronectidae (Righteye Flounders)	Winter Flounder	*Pseudopleuronectes americanus*
	Witch Flounder	*Ictalurus nebulosus**
	American Plaice	*Hippoglossoides platessoides**
	Atlantic Halibut	*Hippoglossus hippoglossus**
	Yellowtail Flounder	*Limanda ferruginea**
	Smooth Flounder	*Liopsetta putnami*
Esocidae (Pikes)	Chain Pickerel	*Esox niger*
Cyprinidae (Minnows)	Golden Shiner	*Notemigonus crysoleucas*
	Creek Chub	*Semotilus atromaculatus*
Catostomidae (Suckers)	White Sucker	*Catostomus commersoni*
Centrarchidae (Sunfishes)	Pumpkinseed	*Lepomis gibbosus*
	Bluegill	*Lepomis macrochirus*
	Largemouth Bass	*Micropterus salmoides*
Ictaluridae (Bullhead Catfishes)	Brown Bullhead	*Ictalurus nebulosus*
Sphyraenidae (Barracudas)	Northern Barracuda	*Sphyraena borealis*
Triglidae (Sea Robins)	Northern Sea Robin	*Prionotus carolinus**
Anarhichadidae (Wolffishes)	Atlantic Wolffish	*Anarhichas lupus**
Hemitripteridae (Sea Ravens)	Sea Raven	*Hemitripterus americanus**
Lophiidae (Monkfishes)	Monkfish	*Lophius americanus**
Ophidiidae (Cusk eels)	Fawn Cusk-eel	*Lepophidium profundorum**
Scorpaenidae (Rockfishes)	Acadian Redfish	*Sebastes fasciatus**

CHAPTER 12

Birds

CHARLES LUBELCZYK AND KATE O'BRIEN

Southern Maine has a rich and diverse faunal community, largely due to the meeting and blending of two distinct ecosystems, the oak-pine ecosystems of the North Atlantic coast and the more northern softwood-dominated ecosystems to the north. Wells NERR lies within this unique transition zone. Particularly diverse in undeveloped habitats is the bird population that occurs along the coastal strip of southern Maine. Although the area has historically been under development pressure, areas such as Wells NERR serve as important sanctuaries both as breeding sites and as stopover habitat for migrating birds. The Wells Reserve is considered part of US Fish and Wildlife Bird Conservation Region (BCR) 30 (USFWS 2006). This region, extending from extreme southwestern Maine to Virginia, is over 9 million ha in size and includes coastal habitats as well as marine habitats out to the continental shelf (USFWS 2002). Bordering this region is BCR 14, which extends from southern Maine through maritime Atlantic Canada. Within this area, it is possible to see a wide variety of species that are conservation targets for both BCR 30 and BCR 14. These target species include the American black buck, piping plover and salt marsh sharptailed sparrow.

In this chapter, we will discuss the avian communities and their habitats present at Wells NERR. Although each habitat described might have particular indicator species, it is common for birds to travel through and utilize a variety of habitats during breeding, migration and wintering seasons, as food resources improve or decline during the year. Currently, over 250 species of birds have been observed on the Reserve, either through passive sighting or through intensive surveys. Management recommendations for avian species of concern are presented.

HISTORY OF STUDIES AT WELLS NERR

Beginning in 1988, Wells NERR incorporated a bird banding program on the premises as part of its upland surveys. Although initially located in an outlying parcel known as the "Alheim Commons" in its first year, the program was moved to a central location on the Reserve, with 10 twelve-meter mist

Figure 12-1: US Fish and Wildlife Bird Conservation Regions 14. Source US Fish and Wildlife Service.

nets located in second-growth forest and successional field habitat. The mist-netting program, conducted by J. M. Ficker (USFWS Master Bander Permit #21419), surveys for breeding birds weekly from the last week of May through August. In 1990, this banding program became a site for the Monitoring Avian Productivity and Survivorship (MAPS) administered by the Institute for Bird Population Studies, headquartered in Point Reyes, California. A complement to this program was the addition of a banding program monitoring abundance of saw-whet owls (*Aegolius acadicus*) in 1994. This banding program, conducted from late September through November, bands owls migrating south along the coastal corridor. Wells NERR is also a site used by the Audubon Society for its annual Breeding Bird Survey conducted in June and the Christmas Bird Count.

Generally, standardized surveys for birds have focused on upland species at Wells NERR, despite its proximity to coastal waters. An informal survey of waterfowl and shorebirds was conducted by volunteers of the Reserve in the 1990's. These surveys began as a project investigating the feeding behavior of large wading birds (primarily great blue herons and snowy egrets), finding that the birds favored less developed areas with a high density of pools and channels (S. Walker, unpublished data, 1991).

Figure 12-2: US Fish and Wildlife Bird Conservation Region 30. Source US Fish and Wildlife Service.

Annual monitoring of large wading birds continued during the summer months through 2001. Wading birds can be considered an indicator species for salt marsh ecosystem state, given that

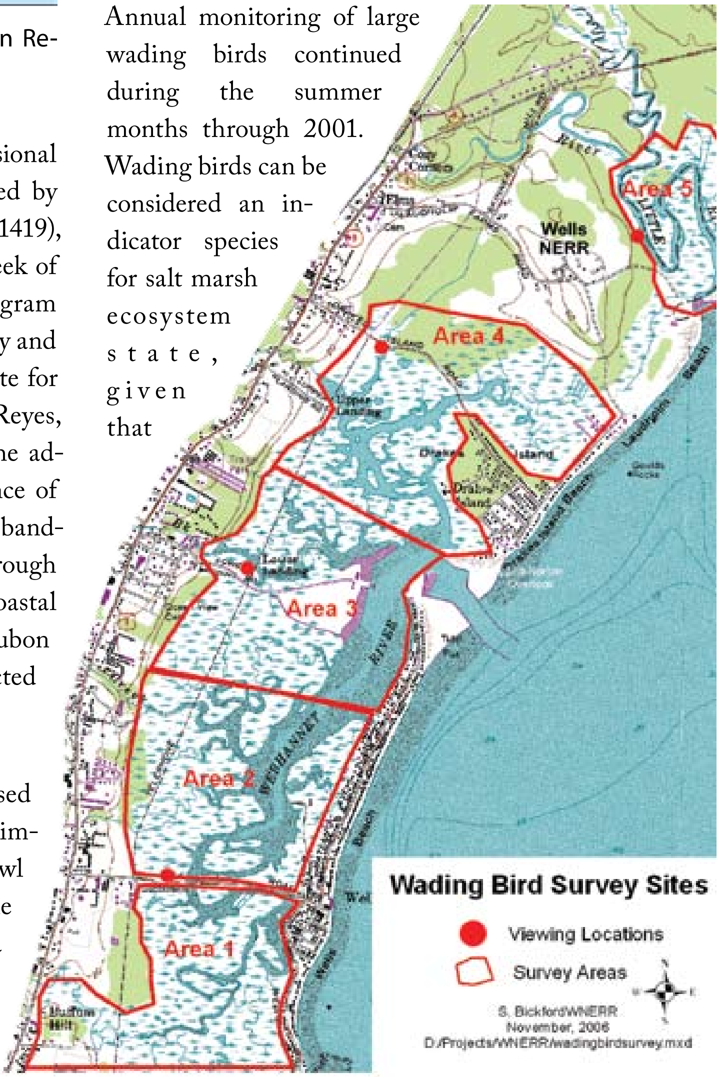


Figure 12-3: Map of Wading Bird Survey Sites. Areas 1, 2, 3 and 4 are on the Webhannet marsh, and Area 5 is on the Little River marsh.

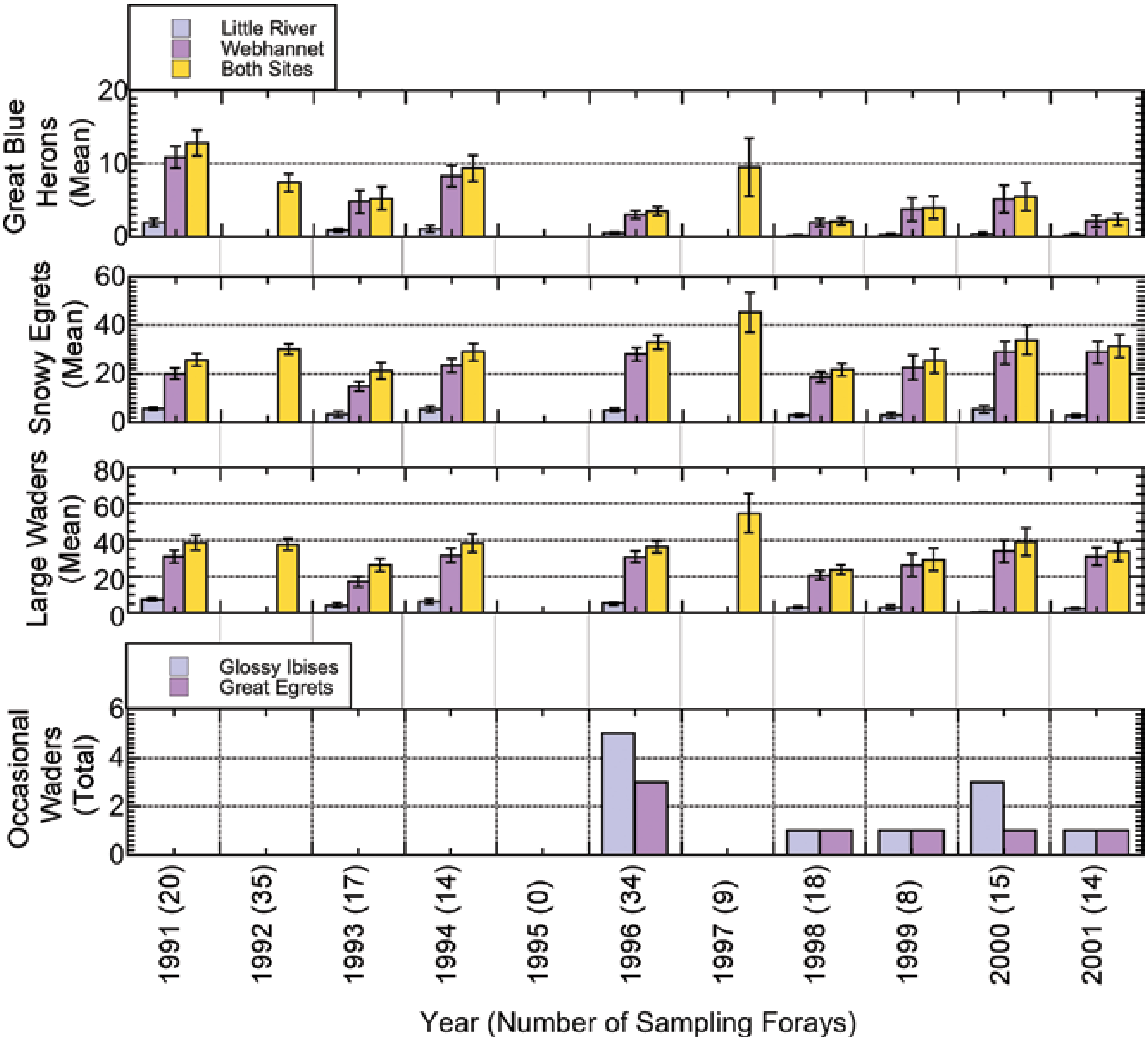


Figure 12-4: Means and standard errors of the number of large wading birds observed on the marshes of Wells NERR during daylight high tide. Note variation in vertical scale and absence of data for 1995. Number of surveys indicated in parentheses after year. Figure Hannah Wilhelm.

they are top predators in the marsh food web, based on the hypothesis that their populations are linked to prey abundance in Gulf of Maine coastal wetlands, as they are in the southeastern states. Large wading bird abundance is being used as one of the primary indicators of ecosystem status and change for the extensive and long-term effort to restore the Florida everglades and other South Florida wetlands (Williams and Melvin 2005). The rationale for using this group as an indicator is based on the linkage between hydrology, prey abundance (fish and crustaceans) and bird population size (Ogden 1994, Gawlik 2002, Cook and Call 2006). Although there are many more wader species using coastal wetlands in the southeast than in the Gulf of Maine, snowy egrets and great blue herons show both numerical and population responses to increased prey abundance from a number of studies in Florida and one in Louisiana (Fleury and Sherry 1995).

From June to September volunteers and interns counted all large wading birds on the high marsh (including high marsh pools) of the Webhannet and Little River estuaries, working from several observing stations (Fig. 12-3). Birds were counted using a spotting scope and

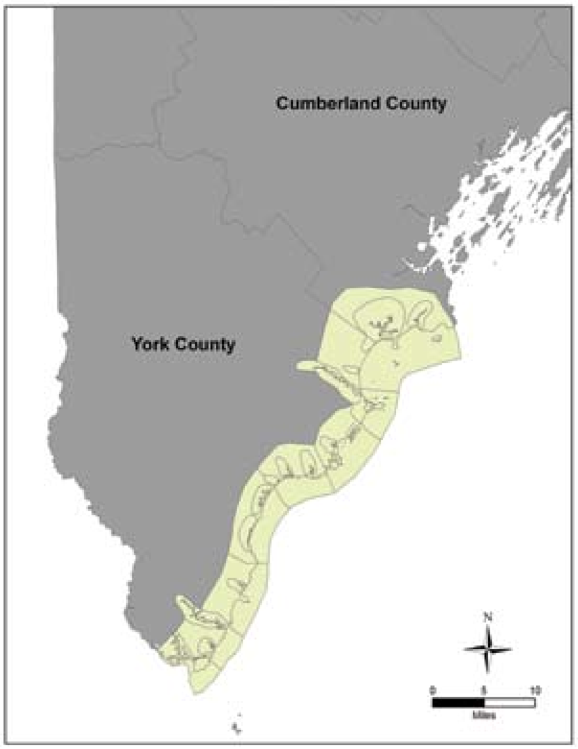


Figure 12-5: Mid-Winter Waterfowl Survey Unit 8 encompasses the coastline of Wells NERR. Data U.S. Fish and Wildlife.

high-powered binoculars, and the approximate location of each individual was marked on a map. Surveys were conducted at high tide, when all waders are visible on the marsh surface.

Ten years of wading bird surveys reveal a potential downward trend in the number of great blue herons observed but a steady population of wading birds overall (Fig. 12-40). During the survey period, the mean number and standard error of great blue herons observed on the Reserve's estuaries was $\bar{x}$ = 6.1 ±1 SE while that for snowy egrets was $\bar{x}$ = 29 ±2 SE.

The administrative boundary of the Reserve includes lands owned and managed by the United States Fish and Wildlife Service Rachel Carson National Wildlife Refuge (USFWS-RCNWR). For this chapter we will draw upon RCNWR datasets and studies. A limited number of aerial waterfowl surveys have been conducted within the Reserve boundaries from 1998-2002. The Reserve also falls within Unit 8, for the annual mid-winter waterfowl survey (Fig. 12-5). RCNWR has conducted surveys and studies of the sharp-tailed sparrows (*Ammodramus caudacutus* and *A. nelsonii*) and other salt marsh birds breeding within the Reserve, and has cooperatively monitored the federally threatened, state endangered piping plover and the state endangered least tern which both nest upon Laudholm Beach.

A nest, most likely belonging to a willet, photographed in the Wheeler marsh. Photo Wells NERR.

HABITATS

Forest

According to Widoff (1985), forest habitat on Wells NERR can be characterized into four categories - red maple swamps, oak-pine forests, pine barrens, and mixed second-growth forest. Red maple (*Acer rubrum*) swamp habitat is common on the Reserve, frequently found adjacent to salt marshes in the lowland areas. Red maple, while the dominant canopy tree, can be found mixed with black cherry (*Prunus serotina*), red spruce (*Picea rubens*) and white birch (*Betula papyrifera*), and, occasionally, yellow birch (*Betula allegheniensis*). In some areas, a substantial shrub layer, composed of native blueberries (*Vaccinuim* spp.) alders (*Alnus rugosa*) and winterberry holly (*Ilex verticillata*) exists. Just as often, the shrub layer might be formed on non-natives, particularly Japanese barberry (*Berberis thunbergii*) and European buckthorn (*Rhamnus cathartica*). Common passerine birds found in these areas are shrub-nesting or ground-foraging songbirds including common yellowthroats (*Geothlypis trichas*), chestnut-sided warblers (*Dendroica pensylvanica*), black-throated green warbler (*Dendroica virens*), American redstarts

(*Setophaga ruticilla*), veeries (*Catharus fuscecens*), northern waterthrush (*Seirus noveboracensis*), eastern towhees (*Pipilo erythrophthalmus*), catbirds (*Dumetella carolinensis*), alder and willow flycatchers (*Empidonax* spp.). The proximity to marshes also allows for the occasional presence of harriers (*Circus cyaneus*) while adjacent fields might attract red-tailed hawks (*Buteo jamaicensis*) into these forests. Higher canopy species such as the ubiquitous black-capped chickadee (*Poecile atricapillus*), the uncommon blackburnian warbler (*Dendroica fusca*), and black-billed cuckoo (*Coccyzus erythroptalmus*) may also occur. In the forested wetlands American woodcock (*Scolopax minor*) utilize this habitat to forage for earthworms.

Pine forests may be classified into two distinct types on the Reserve, pine plantations composed of either eastern white pine (*Pinus strobus*) or red pine (*Pinus resinosa*) in upland areas. Little or no shrub layer exists in these forests. Along the immediate coastal portions of the Reserve, a band of maritime forest characterized by pitch pine (*Pinus rigida*) and scrub oak (*Quercus ilicifolia*) is present. Common shrub layer vegetation in this forest includes bayberry (*Myrica pennsylvanica*), poison ivy (*Toxicodendron radicans*) and roses (*Rosa* spp.). Found in these forests are the black-capped chickadee, tufted titmice (*Baeolophus bicolor*), white-breasted and red-breasted nuthatch (*Sitta* spp.), brown creeper (*Certhia americana*), American crow (*Corvus brachyrhynchos*), and blue jays (*Cyanocitta cristata*). The tallest pines can serve as roosts for raptors or other predators such as crows. Avian predators at Wells NERR in this habitat include the red-tailed hawk, broadwing hawk (*B. platypterus*), barred owl (*Stryx varia*), and northern saw-whet owl. Pine plantations also provide a seasonal refugium for wild turkeys (*Meleagris gallopavo*), who congregate near these forests in winter for thermal protection and for the benefit of reduced snow pack.

Fresh holes mark the presence of a pileated woodpecker. Photo Scott Richardson.

Oak-pine forests are dominated by eastern white pine and red oak (*Quercus rubra*). An intermittent shrub layer might contain high-bush blueberry (*Vaccinium corymbosum*), Japanese barberry, or black huckleberry (*Gaylussacia baccata*). This area is noted for its high canopy, abundant mast crop from acorns, and the resulting snags that appear as mature trees die. Although many types of trees are utilized by woodpeckers on the Reserve, this habitat produced suitably large cavities to accommodate the largest species on the Reserve, the pileated woodpecker (*Dryocopus pileatus*). Other woodpeckers commonly seen in this habitat and other forest types include downy woodpeckers (*Picoides pubescens*), hairy woodpeckers (*Picoides villosus*), yellow-bellied sapsuckers (*Sphyrapicus varius*), and northern flickers (*Colaptes auratus*). Cavities begun by woodpeckers might later be occupied by saw-whet owls, as the predators move into the area. Figure 12-6 illustrates numbers of saw-whet owls mist-netted in oak-pine forests at the Reserve over an eleven-year span.

Second-growth forests on the Reserve are usually a combination of the three other types of forest listed above. Canopy species frequently include red maple, red oak, and eastern white pine but may also have quaking aspen (*Populus tremuloides*) in younger portions of the forest. Apple trees (*Malus* spp.), remnants of orchards overtaken by the successional process, also appear intermittently as a mid-canopy species. The shrub layer in this forest can be extremely dense at some points, consisting primarily of three non-native species: barberry (Common and Japanese), honeysuckle (*Lonicera* spp.), and Asiatic bittersweet (*Celastrus orbiculatus*). The songbird community in this habitat is diverse, with many of the species found in other forests types also using these woods. Many woodpeckers, thrushes, sparrows, and warblers might be found using the shrub layer as cover or forage. Of particular interest is the presence of the blue-winged warbler (*Vermivora pinus*), black and white warbler (*Mniotilta varia*), yellow-rumped warbler (*Dendroica coronata*), Canada warbler (*Wilsonia canadensis*), song sparrow (*Melospiza melodia*), Lincoln's sparrow (*M. lincolnii*), scarlet tanager (*Piranga olivacea*), eastern towhee, wood

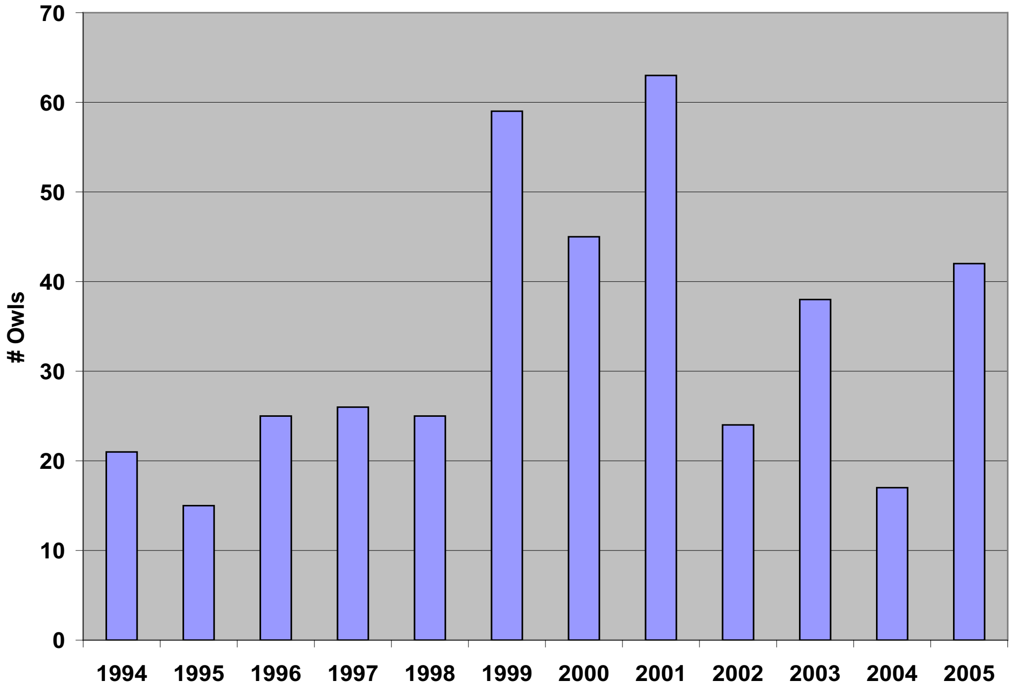


Figure 12-6: Numbers of northern saw-whet owls banded on Wells NERR from Sept-Nov. 1994-1995. Courtesy of June M. Ficker.

thrush (*Hylocichla mustelina*), hermit thrush (*Catharus guttatus*), and rose-breasted grosbeak (*Pheucticus ludovicianus*). Remnant apples and cherries also provide forage for ruby-throated hummingbird (*Archilochus colubris*), the only hummingbird found in New England. Woodcock, turkey (*Melegarus galloparo*), and pheasant (*Phasianus colchicus*) nests might also be found here, if in the vicinity of field habitat. The abundant small mammal community provides forage for hawks and owls, particularly barred, saw-whet, and great horned owls (*Bubo virginianus*). Cooper's hawks (*Accipiter cooperii*) and sharp-shinned hawks (*Accipiter striatus*) may also be found hunting for passerines in these forests.

Saltmarsh sharp-tailed sparrow. Photo Wells NERR.

Fields

Managed fields compose an important part of the upland community at Wells NERR. For some birds, mown or managed fields are absolutely critical. The acknowledged loss of this habitat in the northeast through development or succession makes it critical to maintain fields in the future. Noticeably, the most prominent birds that use mown fields at Wells NERR are bobolinks (*Dolichonyx oryzivorus*). Several areas adjacent to the developed portions of the Reserve serve as breeding and foraging habitat for this species, regionally in decline (Bollinger and Gavin 1992). Other birds that are found in this habitat include the eastern meadowlark (Sturnella magna), field sparrows (*Spizella pusilla*), Eastern kingbird (*Tyrannus tyrannus*), and American woodcock, which are also declining in the region (USFWS, 2006), in addition to barn swallows (*Hirundo rustica*), tree swallows (*Spizella arborea*), wild turkey, and bluebirds (*Sialla sialis*), whose abundance is apparently increasing due to placement and maintenance of nest boxes. Although the above mentioned species utilize mown fields during the breeding

A single snowy egret feeding in a marsh pool. Photo B.A. King.

season, Wells NERR also has birds that use this habitat in their wintering grounds. Three conspicuous winter visitors using the low grasses are the snow bunting (*Plectrophenax nivalis*), dark-eyed junco (*Junco hyernalis*), and rarer Lapland longspur (*Calcarius lapponicus*). Two other, less desirous, species can be found in mown fields year round at the Reserve, European starlings (*Sturnus vulgaris*), and house sparrows (*Passer domesticus*).

Shrublands and Thicket

Successional fields abound at Wells NERR, of varying age. Dominated primarily by non-native vegetation such as barberry, honeysuckle and bittersweet, but containing remnant apple, cherry, alder, rose, bayberry, and blueberr as well, this habitat is critical for many species of birds that use shrubs for forage and cover. Nine species listed as highest or high conservation priority within BCR 30 are shrubland-dependant species. At the Wells Reserve, eight of these species have been documented (American woodcock, prairie warbler [*Dendroica discolor*], blue-winged warbler, brown thrasher [*Toxostoma rufum*], Eastern towhee, field sparrow [*Spizella pusilla*], whip-poor-will [*Caprimulgus vociferus*] and willow flycatcher [*Empidonax traillii*]) (USFWS 2006). Many species found here are in decline across the northeast because of habitat loss from succession and development pressure. In fact, many sparrows, including song sparrows, field sparrows, and white throated sparrows are found in this habitat. Species that are abundant in successional habitats include brown thrashers, catbirds, common yellowthroat, and mockingbirds (*Mimus polyglottos*) as well as cedar waxwings (*Bombycilla cedrorum*) that take advantage of the many fruiting shrubs in the breeding season. The presence of barberry give pheasants and turkey a soft mast crop during the fall season and might provide shelter and potential nest sites for passerines (Schmidt and Whelan 1999). Barberry is thought to be a low quality food source for wildlife, although its berries do persist into winter when other foods may be unavailable (Stiles 1980).

Along with successional habitats, maritime shrublands which grow along the buffer of the upland habitats and the salt marsh consist of many species with high wildlife food value. Bayberry, roses, viburnums and other fruiting shrubs offer habitats critical to migratory landbirds.

Freshwater Marshes

Freshwater marsh habitat is limited within the Reserve. There are several small pockets of freshwater marsh either bordering salt marsh habitat or where tidal flow is restricted. Virginia rail (*Ramis limicola*), green heron (*Butorides virescens*) and the occasional American bittern (*Botaurus lentiginosus*) can occur in these areas during the breeding season and during migration.

Tidal Marshes

Within the boundaries of the Wells NERR, tidal marsh, estuary and tidal river habitats are common. The Wells and Ogunquit marsh complexes (Moody, Wells, Little River and Mousam River) together comprise the second largest salt marsh complex within the State of Maine and are designated as a Focus Area of State-wide Significance due to exemplary habitat within the area. This marsh complex is well over 1,500 acres, although the some parcels remain in private ownership, and the Mousam River portion lies outside of the Reserve boundary. In addition to the salt marsh habitats, the Reserve includes seven tidal mainstem channels and tributaries, providing excellent habitat for waterfowl, waterbirds, shorebirds, raptors and passerines.

The area's prime importance to waterfowl is as a migratory and wintering habitat, although a small number of mallards (*Anas platyrhynchos*), black ducks (*Anas rubripes*), common eider (*Somateria mollissima*) and resident geese utilize the marshes and estuaries during the breeding season. However, during migration it is not uncommon for hundreds of black ducks to be observed utilizing the

A pair of piping plovers. Photo Ted Cunningham.

salt marsh habitats. For the winter months, black ducks are joined by common loons (*Gavia immer*), common goldeneye (*Bucephala clangula*), buffleheads (*Bucephala albeola*), long-tailed ducks (*Clangula hyemalis*), common eiders, mallard, North Atlantic Canada geese (*Branta canadensis*) and red-breasted mergansers (*Mergus serrator*). American black ducks are a species of the highest conservation priority within BCR 30.

The tidal habitats also offer high quality habitats for shorebird species. Several priority shorebirds regularly occur within the salt marsh and mudflat habitats within the Reserve, including sanderling (*Calidris alba*), greater yellowlegs (*Tringa melanoleuca*), semi-palmated sandpipers (*Calidris pusilla*), short-billed dowitchers (*Limnodromus griseus*), among others. Willet (*Catoptrophorus semipalmatus*), a species of high conservation priority, is a common breeder within these marsh complexes as well.

At this time, monitoring of the entire marsh system is not possible; however, some selected areas are surveyed during migration for shorebird use by Rachel Carson National Wildlife Refuge staff. The data for the Oxcart Lane area (Fig. 12-7) is submitted for inclusion within the International Shorebird Survey (ISS) database.

Tidal marshes and rivers provide feeding areas for a diversity of marsh and wading birds. Green heron, great blue heron, snowy egrets, great egrets, glossy ibis, and little blue heron nest on Maine's offshore islands, but feed within the Reserve's salt marsh habitats.

Salt marsh and Nelson sharp-tailed sparrows nest in the tidal marshes of the Reserve, and in certain areas occur in great concentrations. Salt marsh sharp-tailed sparrows are obligate salt marsh species, are range restricted, with breeding occurring only from the Weskeag River in Maine to Virginia (Hodgman et al. 2002, Greenlaw and Rising, 1994). They are of great conservation concern. Nelson sharp-tailed sparrows nest in coastal salt marshes from Parker River National Wildlife Refuge Massachusetts, northwards into Canada (Hodgman *et al.* 2002). In the midwest, Nelsons will also nest in freshwater marshes. The salt marsh sharp-tailed sparrow (pictured) is considered globally vulnerable to extinction according to the IUCN Red List criteria, and is listed as one of the top conservation priorities for BCR 30. Nelsons are also of conservation concern, but their populations are believed to be more secure. Rachel Carson National Wildlife Refuge has been surveying sharp-tailed sparrows for the past 8 years and will be completing a trend analysis in 2007.

Of particular interest, the Reserve falls within the area where these two species meet, overlap and hybridize

	Piping Plover Pairs and Productivity			**Least Terns Pairs and Productivity**		
Year	**Laudholm**	**Crescent Surf**	**Entire State**	**Laudholm**	**Crescent Surf**	**Entire State**
1997	1 (2)	4 (13)	47 (93)	0	20 (1)	50 (11)
1998	2 (3)	3 (6)	60 (88)	1 (2)	20 (7)	86 (12)
1999	4 (11)	4 (4)	56 (91)	20 (20)	40 (45)	62 (67)
2000	6 (14)	3 (6)	50 (80)	37 (17)	85 (62)	126 (81)
2001	4 (14)	5 (14)	55 (109)	15 (#)	102 (57)	120 (63)
2002	5 (15)	5 (6)	66 (91)	12 (#)	81 (145)	121 (155)
2003	6 (10)	8 (0)	61 (78)	20 (0)	57 (8)	156 (66)
2004	5 (3)	3 (4)	55 (80)	1 (0)	50 (3)	146 (69)
2005	1 (1)	6 (5)	49 (27)	4 (1)	52 (7)	114 (20)
2006	0	5 (4)	40 (54)	0	30 (10)	134 (26)

Table 12-1: Piping Plover and Least Tern numbers and productivity at Wells NERR and in the state of Maine. Pairs (Fledglings), # Fledglings counted within Crescent Surf total. Data from Jones *et al.* (2005).

A least tern in flight. Photo Scott Richardson.

(Shriver *et al*. 2005, Hodgman *et al*. 2002). Management issues identified for sharp-tailed sparrows include sea level rise, mercury contamination, disturbance, habitat degradation and invasive plants.

Sandy Beach and Dune

Laudholm Beach is one of the last remaining undeveloped stretches of primary dune and sandy beach within Southern Maine. It is approximately 1.2 km long and is an important breeding area for the federally threatened, state endangered, piping plover and the state endangered least tern. The area has been designated by the state of Maine as essential habitat for least tern and piping plover. Essential habitat receives regulatory protection under the Maine Endangered Species Act which requires that no state agency or municipal government shall permit, license, fund or carry out projects that would significantly alter the habitat or violate protection guidelines adopted for the habitat (12 MRSA Part 13, Subchapter 3 - Endangered Species).

Piping plover (*Charadrius melodus*) populations have been monitored within the state of Maine since 1981. The first nesting pair of plovers was recorded for Laudholm Beach in 1991 and the beach has had piping plovers nesting on it from 1991-2005 (Table 12-1, Jones *et al* 2005). In 2006, there was no nesting activity documented, although plovers did use the area for feeding and migration. Crescent Surf Beach, which lies directly east of Laudholm Beach, (across the Little River inlet) and is connected to Laudholm Beach on spring low tides, but is not within the Reserve boundary, had 5 pairs of nesting plovers which fed in the mudflats of Laudholm Beach. The two areas together make up an important area for plovers within the State.

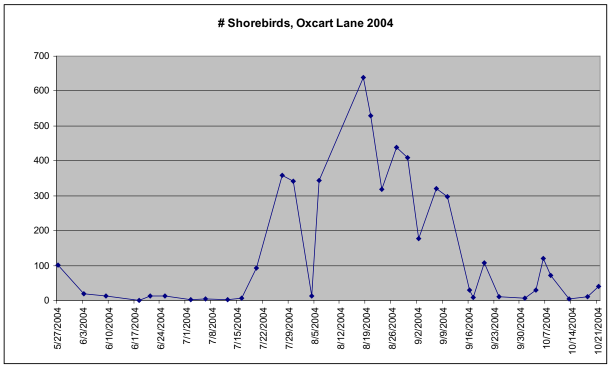


Figure 12-7: Data from the Oxcart Lane surveys conducted in 2004 (K. O'Brien unpublished data).

Least terns (*Sterna antillarum*) are listed as state-endangered and are a species of high conservation priority for USFWS and have been monitored within the state since 1977. Least terns have a dynamic nesting strategy; colony shifts are common responses to changes in habitat or disturbance from predators or people. Least terns reach the most northern portion of their range here in southern Maine. Gathering accurate population estimates for the state is difficult due to their dynamic nesting habits; however, the population estimate has ranged from 50 pairs to 156 pairs within the state over the past 10 years. Laudholm has provided breeding habitat for 1 – 37 pairs within the same time frame. However, the Laudholm and Crescent Surf beaches function biologically as one

Looking for birds on the marsh. Photo Scott Richardson.


Determining the age of a saw whet owl by its wing feathers. This is a second-year bird. Photo June Ficker.

colony, and the two sites together generally host the bulk of least terns nesting within the State.

In recent years, predators and beach erosion have depressed the nesting activity for plovers and terns at Laudholm Beach. In 2006, there were no nesting plovers or terns present and the habitat available to them was of exceedingly low quality. Beach erosion has left only a small band of sandy habitat for nesting, which is not attractive to the birds. Predators further depressed productivity at the adjoining Crescent Surf Beach. The Piping Plover Recovery Plan calls for a minimum productivity of 1.5 fledglings per a pair to ensure plover population growth. For 7 out of the past 10 years Laudholm has met or exceeded those productivity measures. However, recent years have fallen well below that standard.

The area is also an important staging area for common and roseate terns before they begin their fall migration south. Roseate terns are federally and state endangered. Hundreds of common terns and up to twenty roseate terns have used the area to stage for fall migration. In addition to a late summer/fall staging area for terns, the area is also an important roost and feeding area for migratory shorebirds. In 2006, hundreds of semipalmated plovers, semipalmated sandpipers, peeps, and sanderlings were documented using Laudholm Beach as a roost area.

Coastal Waters

Direct coastline within the Reserve's boundary is somewhat limited, with the exception of Laudholm Beach. However the protected salt marshes and estuaries within the boundaries directly benefit the bird resources utilizing coastal waters. During the fall and during the winter months hundreds of waterbirds use coastal waters for feeding and rafting.

As part of waterfowl monitoring the state of Maine and USFWS conduct a winter waterfowl survey in early January (Table 12-2). These surveys serve as an index for the population and are a good indication of the wintering waterfowl that inhabit the coastal waters of

	Mallard	BlackDuck	Common Goldeneye	Bufflehead	Long-tailed Duck	All Scoters	Common Eiders	Mergansers	Canada Geese
2005	**283**	**2015**	**115**	**132**	**95**	**669**	**3427**	**65**	**394**
2004*	**839**	**2720**	**310**	**294**	**161**	**34**	**2353**	**91**	**760**
2003	**514**	**1974**	**174**	**241**	**148**	**959**	**2908**	**104**	**392**
2002	**880**	**2665**	**221**	**224**	**341**	**116**	**6626**	**958**	**529**
2001	**419**	**710**	**71**	**103**	**224**	**510**	**4477**	**126**	**567**
2000	**221**	**1014**	**117**	**77**	**301**	**850**	**5129**	**434**	**402**

** In 2004, the mid-winter waterfowl survey had insufficient funds, and was cancelled. Some dollars were found to do a minimal survey of important black duck habitats, so much of the coast and marsh was flown.*

Table 12-2: Selected Species Documented in the Mid-Winter Waterfowl Survey for Unit 8.

the Reserve. Portions of the Reserve lie within Unit 8 and this unit is further broken down into subunits. In addition to waterfowl, the coastal waters are home to wintering common and red-throated loon (*Gavia stellata*). Total waterfowl observed in 2005 was 7,857. Midwinter waterfowl counts vary greatly depending on weather and ice conditions. Numbers are useful for interpretation over long time intervals.

RESEARCH OVERVIEW

Role of Birds in Lyme Disease Ecology

As part of an effort to better understand the complex ecology of Lyme disease and its vector tick, *Ixodes scapularis*, information on tick burdens and infection rates were collected beginning in 1989 from breeding passerine birds. Collected in 12-meter mist nests, each bird is individually numbered, sexed, aged, and reproductive status recorded. Ticks are removed and identified to species at the Maine Medical Center Research Institute in South Portland, Maine. Suitable specimens are examined by darkfield microscopy for the presence of the spirochete that causes Lyme disease, *Borrelia burgdorferi*. Rand *et al*. (1998) found that many species of ground nesting and shrub foraging birds may host ticks and some, such as common yellowthroats and veeries, may act as reservoirs for the bacteria in nature while other species such as catbirds, are inefficient reservoirs of *B. burgdorferi*.

Migratory Studies of Owls

Collaborating with Dr. Keith Hobson of the Prairie and Northern Wildlife Research Center, Environment Canada in Saskatoon, SK Canada, bird banders at the Reserve have collected samples for isotope analysis on feathers plucked from northern saw-whet owls. Owls banded during the fall southward migration or on wintering grounds can be traced back to their previous summer grounds using stable isotope analysis of feather protein. By analyzing feathers grown during the previous year, researchers can study population movement patterns.

HUMAN INFLUENCES

Deer

The abundance of white-tailed deer (*Odocoileus virginianus*) in south coastal Maine has been a concern of both natural resource managers and public health professionals. In addition to its role in the ecology of Lyme disease, deer overabundance has been linked to songbird declines

Removal of a tick from a male, second-year returning rufous-sided towhee, originally banded at Wells NERR in 2005. Photo June Ficker.

in northeastern forests (DeCalesta 1994). It has been estimated that deer densities over 7.9 km^{-2} begin to show adverse effects on the vegetation community and impact bird populations, primarily those species utilizing the ground and lower shrub layers. The most recent estimate of deer density at Wells NERR placed deer densities over 40 km^{-2}. Until 2002, deer hunting was prohibited on Wells NERR because of its status as a state game sanctuary, a provision that dated to the 1930's.

Invasives

The former agricultural use of the property that was to become Wells NERR allowed for the colonization of many of the exotics that plague the Reserve today. Many, including barberries, honeysuckles, and bittersweet, were imported in the 1800's from Europe or Asia. Finding little competition or predators, these plants thrived.

Habitat Loss

In addition to being the most ecologically diverse region of Maine, south coastal Maine also contains the highest human population. Coastal parcels have increased in dramatically in economic value, making land conservation much more difficult as development pressures increase.

A male Wilson's warbler. Photo June Ficker.

Human and avian prints side by side on Laudholm Beach. Photo by Susan Bickford.

RESEARCH NEEDS

Effects of Landscape Change

Efforts to control invasives and exotics, while a priority for upland management at the Reserve, have not been associated with the abundance of bird populations. Previous research has demonstrated that nesting success increases and predation decreases in association with exotic vegetation (Schmidt *et al.* 2005) or that presence of exotics decreases nesting success of songbirds (Borgmann and Rodewald 2004). Regardless of effects on songbirds, upland game birds such as turkey and pheasant benefit from the presence of soft mast crops produced by barberries in the fall (Stiles 1980).

Mercury within Salt Marsh Passerines

Exceedingly high levels of mercury have been detected in the blood of salt marsh sharp-tailed sparrows nesting within the Reserve salt marshes (Shriver *et al.* 2006, Lane and Evers 2005). Additional research is necessary to determine the pathways of mercury for this species

Obtaining a cloacal swab from a veery. Photo June Ficker.

and if mercury impacts productivity or survival of the species.

Reducing Predation on Piping Plovers and Terns

Predation of the nests and chicks of plovers and terns has limited the ability of plovers nesting within the Reserve to meet recovery plan productivity criteria. Identification of predators responsible for nest and chick loss and determination of the best course of management action is a complex problem. Suites of predators appear to change on an annual basis, although some like crow are documented repeat offenders at the adjoining Crescent Surf Beach.

Beach Processes

In recent years Laudholm Beach has experienced serious beach erosion. The exact cause of that erosion is unclear. However, there have been changes in sea walls within the immediate area which could have resulted in changes in sand transport. In 2005, Nor'easters, which generally are winter storms, hit the beaches in the spring, further reducing the sandy habitat which was available for nesting plovers and terns. It is difficult to say if the changes at Laudholm Beach are part of a natural cycle, or influenced by human actions. Currently, much of the sand at Laudholm has been washed away and the beach has a more cobbled, or armored, appearance.

MANAGEMENT RECOMMENDATIONS

◊ Keep fields open for meadowlarks and boblinks. Mow fields after August 1, at a minimum every three years. Consider the use of mowing with periodic prescribed fires to encourage native grasses.

◊ Establish shrubland management units to benefit the suite of declining shrubland dependant birds which breed within the Northeast. Regenerate alder thickets and manage for native shrublands to benefit woodcock and other thicket dwelling birds.

◊ Continue to aggressively reduce the deer population through the use of hunting to enable natural forest regeneration processes and to assist shrub and ground nesting birds.

◊ Consider maintaining old apple orchards by releasing apple trees to benefit wildlife.

◊ Promote salt marsh health and when necessary, restore salt marshes by removing tidal restrictions and invasive plants; providing adequate buffers from upland land uses and runoff, and monitoring water quality.

◊ Reduce disturbance to nesting plovers and terns from people and dogs by working with state game wardens, ensuring signage is adequate and appropriate, and continuing to cooperatively manage the plover and tern population at Laudholm Beach with the assistance of Rachel Carson NWR.

REFERENCES

Bollinger, E.K. and T.A. Gavin. 1992. Eastern Bobolink populations: ecology and conservation in an agricultural landscape. *In* Ecology and conservation of neotropical migrant landbirds *Edited by* Hagan, J. M III and D. W. Johnston. Smithsonian Institute Press, Washington, D.C., pp. 497–506.

Borgmann, K.L. and A.D. Rodewald. 2004. Nest predation in an urbanizing landscape: the role of exotic shrubs. Ecological Applications. 14(6): 1757-1765.

Cook, M.I. and E.M. Call. 2006. South Florida wading bird report. South Florida Water Management District, West Palm Beach, Florida, USA. 46 pp.

deCalesta, D.S. 1994. Impact of White-Tailed Deer on Songbirds within Managed Forests in Pennsylvania. Journal of Wildlife Management 58: 711-718.

Fleury, B.E. and T.W. Sherry. 1995. Long-term population trends of colonial wading birds in the southern United States: the impact of crayfish aquaculture on Louisiana populations. The Auk 112(3): 613-632.

Gawlik, D.E. 2002. The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72(3): 329-346.

Greenlaw, J.S. and J.D. Rising. 1994. Sharp-tailed Sparrow (*Ammodramus caudacutus*). *In* The Birds of North America, No. 112 *Edited by* A. Poole and F. Gill. Philadelphia: The Academy of Natural Sciences; Washington, D.C.: The American Ornithological Union.

Hodgman P., W.G. Shriver and P.D. Vickery. 2002. Redefining range overlap between the sharp-tailed sparrows of coastal New England. The Wilson Bulletin 114: pp. 38-43.

Jones, J., J. Felio, J. Costa and K. O'Brien. 2005 Piping Plover and Least Tern Project Report. 2005. Maine Audubon, Falmouth, ME. 26 pp.

Lane, O.P. and D.C. Evers. 2005. Developing a geographic exposure profile of methylmercury availability in salt marshes of New England. Report BRI 2005-04. Biodiversity Research Institute, Gorham, Maine.

Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. *In* Everglades: the ecosystem and its restoration. *Edited by* S.M. Davis and J.C. Ogden. St. Lucie Press, Delray Beach, Florida. pp. 533-570.

Schmidt, K.A. and C.J. Whelan. 1999. Effects of exotic Lonicera and Rhamnus on songbird nest predation. Conservation Biology. 13: 1502-1506.

Schmidt, K.A., L.C. Nelis, N. Briggs, and R.S. Ostfeld. 2005. Invasive shrubs and songbird nesting success: effects of climate variability and predator abundance. Ecological Applications. 15(1): 258-265.

Shriver, W.G., J.P. Gibbs, Peter D. Vickery, H. Lisle Gibbs, Thomas P. Hodgman, Peter T. Jones, Christopher N. Jacques. 2005. Concordance between morphological and molecular markers in assessing hybridization between sharp-tailed sparrows in New England. Auk 121: 94–107.

Shriver, W.G., D.C. Evers, T.P. Hodgman, B.J. MacCulloch and R.J. Taylor. 2006. Mercury in sharp-tailed sparrows breeding in coastal wetlands. Environmental Bioindicators 1(2): 129-135.

Stiles, E.W. 1980. Pattern of fruit presentation and seed dispersal in bird-disseminated woody plants in eastern deciduous forests. American Naturalist 116: 670-688.

U.S. Fish and Wildlife Service. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, Virginia. 99 pp.

U.S. Fish and Wildlife Service, Mid-Atlantic/Southern New England Bird Conservation Region (BCR 30) Draft Implementation Plan. 2006. 59 pp.

Widoff, L. 1985.The vegetation of the Wells National Estuarine Sanctuary. Maine State Planning Office, Augusta, ME. 45 pp.

Williams, G.E. and S.L. Melvin. 2005. Studies in bird assemblages and federally-listed species of the channelized Kissimmee River, Florida. *In* Establishing a baseline: pre-restoration studies of the channelized Kissimmee River. *Edited by* S.G. Bousquin, D.H. Anderson, G.E. Williams, and D.J. Colangelo. South Florida Water Management District, West Palm Beach, Florida, USA. Technical Publication ERA #432. 141 pp.

Table 12-3: Birds found at Wells NERR.

Family	Common Name	Scientific Name
Gaviidae (Loons)	Red-throated Loon	*Gavia stellata*
	Common Loon	*Gavia immer*
Podicipedidae (Grebes)	Horned Grebe	*Podiceps auritus*
	Red-necked Grebe	*Podiceps grisegna*
Sulidae (Boobies and Gannets)	Northern Gannet	*Morus bassanus*
Phalacrocoracidae (Cormorants)	Double-crested Cormorant	*Phalacrocorax auritus*
	Great Cormorant	*Phalacrocorax carbo*
Ardeidae (Herons, Egrets, and Bitterns)	American Bittern	*Botaurus lentiginosus*
	Great Blue Heron	*Ardea herodias*
	Great Egret	*Ardea alba*
	Snowy Egret	*Egretta thula*
	Little Blue Heron	*Egretta caerulea*
	Tricolored Heron	*Egretta tricolor*
	Green Heron	*Butorides virescens*
	Black-crowned Night-Heron	*Nycticorax nycticorax*
Threskiornithidae (Ibises and Spoonbills)	Glossy Ibis	*Plegadis falcinellus*
Cathartidae (New World Vultures)	Turkey Vulture	*Cathartes aura*
Anatidae (Ducks, Geese, and Swans)	Snow Goose	*Branta caerulescens*
	Canada Goose	*Branta canadensis*
	Brant	*Branta bernicla*
	Mute Swan	*Cygnus olor*
	Wood Duck	*Aix sponsa*
	Gadwall	*Anas strepera*
	American Wigeon	*Anas americanus*
	American Black Duck	*Anas rubripes*
	Mallard	*Anas platyrhynchos*
	Blue-winged Teal	*Anas discors*
	Northern Shoveler	*Anas clypeata*
	Northern Pintail	*Anas acuta*
	Green-winged Teal	*Anas crecca*
	Canvasback	*Aythya valisineria*
	Common Eider	*Somateria mollissima*
	Surf Scoter	*Melanitta perspicillata*
	White-winged Scoter	*Melanitta deglandi*
	Black Scoter	*Melanitta nigra*
	Long-tailed Duck	*Clangula hyemalis*
	Bufflehead	*Bucephala albeola*
	Common Goldeneye	*Bucephala clangula*
	Barrow's Goldeneye	*Bucephala islandica*
	Hooded Merganser	*Lophodytes cucullataus*
	Red-breasted Merganser	*Mergus serrator*
Accipitridae (Hawks, Eagles)	Osprey	*Pandion haliaetus*
	Bald Eagle	*Haliaeetus leucocoephalus*
	Northern Harrier	*Circus cyaneus*
	Sharp-shinned Hawk	*Accipiter striatus*
	Cooper's Hawk	*Acipiter cooperii*
	Northern Goshawk	*Acipiter gentilis*
	Broad-winged Hawk	*Buteo platypterus*
	Red-tailed Hawk	*Buteo jamiaicensis*
	Rough-legged Hawk	*Buteo lagopus*
	Golden Eagle	*Aquila chrysaetos*
Falconidae (Falcons and Caracaras)	American Kestrel	*Falco sparverius*
	Merlin	*Falco columbarius*
	Peregrine Falcon	*Falco peregrinus*
Phasianidae (Grouse, Turkey, Pheasants)	Ring-necked Pheasant	*Phasianus colchius*
	Ruffed Grouse	*Bonasa umbellus*
	Wild Turkey	*Meleagris gallopavo*

Table 12-3 (continued): Birds found at Wells NERR.

Family	Common Name	Scientific Name
Charadriidae (Plovers and Lapwings)	Black-bellied Plover	*Pluvvialis squatarola*
	American Golden-Plover	*Pluvialis dominica*
	Wilson's Plover	*Charadrius wilsonia*
	Semipalmated Plover	*Charadrius semipalmatus*
	Piping Plover	*Charadrius melodus*
	Killdeer	*Charadrius vociferus*
Scolopacidae (Sandpipers and Phalaropes)	American Avocet	*Recruvirostra americana*
	Greater Yellowlegs	*Tringa melanoleuca*
	Lesser Yellowlegs	*Tringa flavipes*
	Solitary Sandpiper	*Tringa solitaria*
	Willet	*Catoptorophorus semialmatrus*
	Spotted Sandpiper	*Actitis macularia*
	Upland Sandpiper	*Bartramia longicauda*
	Whimbrel	*Numenius phaeopus*
	Hudsonian Godwit	*Limosa haemastica*
	Ruddy Turnstone	*Arenaria interpres*
	Sanderling	*Calidris alba*
	Semipalmated Sandpiper	*Calidris pusilla*
	Western Sandpiper	*Calidris mauri*
	Least Sandpiper	*Calidris minutilla*
	White-rumped Sandpiper	*Calidris fuscicollis*
	Pectoral Sandpiper	*Calidris melanotos*
	Purple Sandpiper	*Calidris maritima*
	Dunlin	*Calidris alpina*
	Stilt Sandpiper	*Calidris himantopus*
	Short-billed Dowitcher	*Limnodromus griseus*
	Common Snipe	*Capella gallinago*
	American Woodcock	*Philohela minor*
	Red-necked Phalarope	*Lobipes lobatus*
Laridae (Gulls and Terns)	Laughing Gull	*Larus atricilla*
	Bonaparte's Gull	*Larus philadelphia*
	Ring-billed Gull	*Larus delawarensis*
	Herring Gull	*Larus argentatus*
	Great Black-backed Gull	*Larus marinus*
	Black-legged Kittiwake	*Rissa tridactyla*
	Royal Tern	*Sterna maxima*
	Sandwich Tern	*Sterna sandvicensis*
	Roseate Tern	*Sterna dougallii*
	Common Tern	*Sterna hirundo*
	Forster's Tern	*Sterna forsteri*
	Least Tern	*Sterna albifrons*
	Black Skimmer	*Rynchops niger*
Alcidae (Auks)	Thick-billed Murre	*Uria lomvia*
Columbidae (Pigeons and Doves)	Rock Dove	*Columba livia*
	Mourning Dove	*Zenaida macroura*
Cuculidae (Cuckoos)	Black-billed Cuckoo	*Coxxyzus erythropthalmus*
	Yellow-billed Cuckoo	*Coccyzus americanus*
Strigidae (Typical Owls)	Eastern Screech-Owl	*Otus asio*
	Great Horned Owl	*Bubo virginianus*
	Snowy Owl	*Nyctea scandiaca*
	Barred Owl	*Strix varia*
	Short-eared Owl	*Asio flammeus*
	Northern Saw-whet Owl	*Aegolius acadicus*
Caprimulgidae (Goatsuckers)	Common Nighthawk	*Chordiles minor*
Apodidae (Swifts)	Chimney Swift	*Chaetura pelagica*
Trochilidae (Hummingbirds)	Ruby-thr. Hummingbird	*Archilochus colubris*
Alcedinidae (Kingfishers)	Belted Kingfisher	*Megaceryle alcyon*

Table 12-3 (continued): Birds found at Wells NERR.

Family	Common Name	Scientific Name
Picidae (Woodpeckers)	Yellow-bellied Sapsucker	*Sphyrapicus varius*
	Downy Woodpecker	*Picoides pubescens*
	Hairy Woodpecker	*Picoides villosus*
	Northern Flicker	*Colaptes chrysoides*
	Pileated Woodpecker	*Dryocopus pileatus*
Tyrannidae (Tyrant Flycatchers)	Eastern Wood-Pewee	*Contopus virens*
	Yellow-bellied Flycatcher	*Empidonomus flaviventris*
	Acadian Flycatcher	*Empidonax virescens*
	Alder Flycatcher	*Empidonax alnorum*
	Least Flycatcher	*Empidonax minimus*
	Eastern Phoebe	*Sayornis phoebe*
	Great Crested Flycatcher	*Myiarchus crinitus*
	Eastern Kingbird	*Tyrranus tyrranus*
Laniidae (Shrikes)	Northern Shrike	*Lanius excubitor*
Vireonidae (Vireos)	Yellow-throated Vireo	*Vireo flavifrons*
	Blue-headed Vireo	*Vireo solitarius*
	Warbling Vireo	*Vireo gilvus*
	Red-eyed Vireo	*Vireo olivaceus*
Corvidae (Crows and Jays)	Gray Jay	*Perisoresu canadensis*
	Blue Jay	*Cyanocorax cristata*
	American Crow	*Corvus brachyrhynchos*
	Fish Crow	*Corvus ossifragus*
	Common Raven	*Corvus corax*
Alaudidae (Larks)	Horned Lark	*Eremophila alpestris*
Hirundinidae (Swallows and Martins)	Purple Martin	*Progne subis*
	Tree Swallow	*Tachycineta bicolor*
	No. Rough-winged Swallow	*Stelgidopteryx serripennis*
	Bank Swallow	*Riparia riparia*
	Barn Swallow	*Hirundo rustica*
Paridae (Chickadees and Titmice)	Black-capped Chickadee	*Poecile atricapilla*
	Tufted Titmouse	*Baeolophus bicolor*
Sittidae (Nuthatches)	Red-breasted Nuthatch	*Sitta canadensis*
	White-breasted Nuthatch	*Sitta carolinensis*
Certhiidae (Creepers)	Brown Creeper	*Certhia americana*
Troglodytidae (Wrens)	Carolina Wren	*Thryothorus ludovicianus*
	House Wren	*Troglodytes aedon*
	Winter Wren	*Troglodytes troglodytes*
	Marsh Wren	*Cistothorus palustris*
Sylviidae (Gnatcatchers)	Blue-gray Gnatcatcher	*Polioptila caerulea*
Turdidae (Thrushes)	Eastern Bluebird	*Sialia sialis*
	Veery	*Catharus fuscescens*
	Gray-cheeked Thrush	*Catharus minimus*
	Swainson's Thrush	*Catharus ustulatus*
	Hermit Thrush	*Catharus guttatus*
	Wood Thrush	*Hylocichla mustelina*
	American Robin	*Turdus migratorius*
Mimidae (Thrashers and Mockinbirds)	Gray Catbird	*Dumtella carolinensis*
	Northern Mockingbird	*Mimus polyglottos*
	Brown Thrasher	*Toxostoma rufum*
Regulidae (Kinglets)	Ruby-crowned Kinglet	*Regulus calendula*
	Golden-crowned Kinglet	*Regulus satrapa*
Sturnidae (Starlings and Mynas)	European Starling	*Sturnus vulgaris*
	American Pipit	*Anthus rubescens*
Bombycillidae (Waxwings)	Cedar Waxwing	*Bombycilla cedrorum*
Parulidae (Wood Warblers)	Blue-winged Warbler	*Vermivora pinus*
	Tennessee Warbler	*Vermivora peregrina*
	Orange-crowned Warbler	*Vermivora celata*

Table 12-3 (continued): Birds found at Wells NERR.

Family	Common Name	Scientific Name
	Nashville Warbler	*Vermivora ruficapilla*
	Northern Parula	*Parula americana*
	Yellow Warbler	*Dendroica petechia*
	Chestnut-sided Warbler	*Dendroica pensylvanica*
	Magnolia Warbler	*Dendroica magnolia*
	Black-throated Blue Warbler	*Dendroica caerulescens*
	Yellow-rumped Warbler	*Dendroica coronata*
	Black-thr. Green Warbler	*Dendrocia virens*
	Blackburnian Warbler	*Dendroica fuca*
	Pine Warbler	*Dendroica pinus*
	Prairie Warbler	*Dendroica discolor*
	Palm Warbler	*Dendroica palmarum*
	Bay-breasted Warbler	*Dendroica castanea*
	Blackpoll Warbler	*Dendroica striata*
	Black-and-white Warbler	*Mniotilta varia*
	American Redstart	*Setophaga ruticilla*
	Ovenbird	*Seiurus aurocapillus*
	Northern Waterthrush	*Seiurus noveboracensis*
	Mourning Warbler	*Oporornnis philadelphia*
	Common Yellowthroat	*Geothlypis trichas*
	Hooded Warbler	*Wilsonia citrina*
	Wilson's Warbler	*Wilsonia pusilla*
	Canada Warbler	*Wilsonia canadensis*
Thraupidae (Tanangers)	Scarlet Tanager	*Piranga olivacea*
Emberizidae (New World Sparrows)	Eastern Towhee	*Pipilo erythrophthalmus*
	American Tree Sparrow	*Spizella arborea*
	Chipping Sparrow	*Spizella passerina*
	Field Sparrow	*Spizella pusilla*
	Vesper Sparrow	*Pooecetes gramineus*
	Lark Sparrow	*Chondestes grammacus*
	Savannah Sparrow	*Passerculus sandwichensis*
	Nelson's Sh.-tailed Sparrow	*Amophila nelsoni*
	Salt marsh Sh.-tailed Sparrow	*Ammodramus caudacutus*
	Seaside Sparrow	*Ammodramus maritimus*
	Song Sparrow	*Melospiza melodia*
	Lincoln's Sparrow	*Melospiza lincolnii*
	Swamp Sparrow	*Melospiza georgiana*
	White-throated Sparrow	*Zonotrichia albicollis*
	White-crowned Sparrow	*Zonotrichia leucophrys*
	Dark-eyed Junco	*Junco hyemalis*
	Lapland Longspur	*Calcarius lapponicus*
	Snow Bunting	*Plectophenax nivalis*
Cardinalidae (Cardinals)	Northern Cardinal	*Cardinalis cardinalis*
	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
	Indigo Bunting	*Passerina cyanea*
Icteridae (Blackbirds and Orioles	Bobolink	*Dolichonyx oryzivorus*
	Red-winged Blackbird	*Agelaius phoeniceus*
	Eastern Meadowlark	*Sturnella magna*
	Common Grackle	*Quiscalus quiscula*
	Brown-headed Cowbird	*Molothrus ater*
	Orchard Oriole	*Icterus spurius*
	Baltimore Oriole	*Icterus galbula*
Fringillidae (Finches)	Purple Finch	*Carpodacus purpureus*
	House Finch	*Carpodacus mexicanus*
	Common Redpoll	*Carduelis flammea*
	American Goldfinch	*Carduelis tristis*
Passeridae (Old World Sparrows)	House Sparrow	*Passer domesticus*

CHAPTER 13

Mammals

CHARLES LUBELCZYK AND KATE O'BRIEN

Southern Maine is recognized as the most ecologically diverse region of Maine, both in floral and faunal communities (Krohn *et al.* 1998). The decline of widespread agriculture and pasturage since the 1800's has resulted in many areas reverting to forest (mixed softwoods and hardwoods) and field habitat of different successional stages. These habitats, interspersed with many types of wetlands, provide for a rich community of mammals in southern Maine. Situated in the South Coastal biophysical region of Maine (McMahon and Bernard 1993), Wells has many plants and animals that are common to both more northerly and more southerly locations. In this chapter we shall provide an overview of the mammals found within the habitats of the Wells National Estuarine Research Reserve (Wells NERR) and surrounding areas, and management implications for species of interest.

HISTORY OF STUDIES AT WELLS NERR

Limited studies of mammal populations have occurred at Wells NERR. The most extensively studied mammal at the Reserve has been the white-tailed deer (*Odocoileus virginianus*). The impact of white-tailed deer on forest songbirds, vegetation communities, and their role in the enzootic cycle of Lyme disease has been well documented. In brief, deer are viewed by many researchers as a keystone herbivore in many ecological communities (Waller and Alverson 1997). Deer densities above 7.9 km^{-2} have been attributed to declines in forest songbird abundance (DeCalesta 1994) and have been shown to alter the composition of the forest plant community in favor of browse-resistant or unpalatable vegetation (Redding 1995). Rich (1992), using spotlighting censuses along transects, estimated the density of deer on Wells NERR to be above 60 mi^{-2} (23.1 km^{-2}). A later study by Rand *et al.* (2003) found a strong relationship between deer density and abundance of the Lyme disease vector tick *Ixodes scapularis*, commonly known as the deer tick (Fig. 13-1). This study, estimating deer density based on

White-tailed deer at Wells NERR. Photo Frank Wolfe.

pellet count censuses, estimated the number of deer in the vicinity of Wells NERR to be over 40 km^{-2}.

In addition to the role of white-tailed deer's role in the ecology of Lyme disease, the role of small mammal communities has also been examined. Rand *et al.* (1998) noted the presence of sub-adult deer ticks on small mammals at Wells NERR. In particular, abundance of ticks was greatest on two species of rodents, the white-footed mouse (*Peromyscus leucopus)* and eastern chipmunk (*Tamias striatus*). Hawks (1992) studied the relationship between the white-footed mouse and deer tick as well, finding that Wells NERR had greater burdens of ticks on its mice than a well-established comparison site at Crane's Beach in Ipswich, Massachusetts.

Recently, much attention has been paid to the presence of the New England cottontail (*Sylvilagus transitionalis*) in southern Maine, a species threatened with habitat loss from maturation of forests (Barbour and Litvaitis 1993), habitat fragmentation and scramble competition with a related but introduced species, the eastern cottontail (*Sylvilagus floridanus*) (Probert and Litvaitis 1996). Within Maine, however, the eastern cottontail has not been documented in the wild (Litvaitis *et al.* 2003), making Maine a potentially important refuge for New England cottontail. This lagomorph[1] is proposed for listing under the State Endangered Species Act and has been designated as an official Candidate Species under the Federal Endangered Species Act. Wells NERR has been recognized as a crucial patch of habitat for this species, particularly for its late successional thicket habitat dominated by alder, apple and honeysuckles (Barbour and Litvaitis 1993). Currently, densities are not estimated for this mammal on the Reserve. However, in the winter of 2005 / 2006 the presence of New England cottontail was confirmed with pellet DNA analysis and winter tracking (USFWS, personal communication).

The Reserve's Muskie Trail passes through forests and fields where the careful observer may encounter wild mammals. Photo Scott Richardson.

Embedded tick larvae on white-footed mouse ear (left). Photo Kevin Byron.

UPLAND HABITATS

Forest

Very few species of forest habitat specialists exist on the Reserve. Throughout the forested habitat of the Reserve, a diverse small mammal community exists which includes white-footed mice, pine voles (*Microtus pinetorum*), boreal red-backed voles (*Clethrionomys gapperi*), woodland jumping mice (*Napeaozapus insignis*), masked shrews (*Sorex cinereus*), short-tailed shrews (*Blarina

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[1] **lagomorph** (n) - A rabbit, hare or pika. Refers to the taxonomic order Lagomorpha.

A boreal red-backed vole carrying an embedded, engorged tick. Inset: close-up view of the embedded tick. Photo Maggie Desch.

brevicauda), least shrews (*Cryptotis parva*), gray squirrels (*Sciurus carolinensis*), red squirrels (*Tamiasciurus hudsonicus*), eastern chipmunks (*Tamias striatus*) and southern flying squirrel (*Glaucomys volans*). The southern bog lemming (*Synaptomis cooperi*) has been reported from the region but no specimens have been recorded from Wells NERR. This small mammal community supports a large population of predators, both avian and mammalian, including raptors but also wild canids such as the red fox (*Vulpes vulpes*) and coyote (*Canis latrans*). Mustelids such as ermine or short-tailed weasel (*Mustela erminea*), long-tailed weasel (*Mustela frenata*), fisher (*Martes pennanti*), and striped skunk (*Mephitis mephitis*), as well as raccoons (*Procyon lotor*) also benefit from this prey base. Other predators that might be found on the Reserve on occasion include bobcats (*Lynx rufus*), mink (*Mustela vison*), and gray fox (*Urocyon cinereoargenteus*). Cervids such as deer are abundant in many habitats, frequenting late successional and second-growth forests for cover and oak-maple forests for mast in the fall. Moose are an occasional presence on the Reserve, utilizing deciduous trees for browse.

Oak-pine forests: One of the few mammals truly associated with eastern white pine (*Pinus strobus*) on Wells NERR is the porcupine. This herbivore utilizes conifer trees for food and may damage limbs of trees by gnawing on young branches. Although both the red squirrel and the boreal red-backed vole are considered more typical in coniferous habitats, they are also typical of other forest types at Wells NERR.

Oak-pine forests and second-growth forests provide suitable nesting habitats for bats that use tree cavities and snags. Although no systematic survey of bat populations have been conducted at Wells NERR, southern Maine is

The eastern chipmunk, Tamias striatus, is often seen in the upland forests of Wells NERR. Photo Ward Feurt.

home to many species of Chiroptera including the little brown myotis (*Myotis lucifugus*), the northern long-eared bat (*Myotis septenrionalis*), big brown (*Eptisicus fuscus*), eastern pipistrelle (*Pipistrellus subflavus*), and the red bat (*Lasiurus borealis*) among others. Portions of these forests adjacent to fields also provide hibernation dens for the woodchuck (*Marmota monax*). Mast deposited from the canopies of oaks (*Quercus* spp.) and maples (*Acer* spp.), the dominant trees in these forests, are an important food source for a wide variety of mammals and birds, and complex interactions are believed to exist in the cycles of mast production and abundance of these forest animals (Jones *et al.* 1998, Ostfeld 2002).

Fields and Shrublands

Managed fields are frequented by high densities of meadow voles (*Microtus pennsylvanicus*). Runs of these abundant rodents are seen throughout field habitat, and attract predators such as foxes and coyotes during evening hours.

Successional thickets, having a minimum stem density of shrubs or small trees of > 10,000 stems per hectare, and a preferred stem density of > 20,000 stems per hectare, are ideal habitat for New England cottontail. While small patches of habitat less than 2 ha may be occupied, they are prone to local extinction. Management efforts should also be directed towards management of core habitats of greater than 10 ha or clusters of core habitats (Barbour and Litvaitis 1993; Litvaitis and Villafeurte 1996, Litvaitis *et al.* 2001, 2003, Litvaitis and Tash 2006). Although New England cottontail has often been associated with exotic, invasive shrub species such as honeysuckle (*Lonicera* spp.), Japanese barberry (*Berberis thunbergii*) and multiflora rose (*Rosa multiflora*), it is unknown if these plants provide high-quality habitat and sufficient winter browse. It is recommended that management actions be geared towards the promotion of native shrublands and small trees such as gray birch, red maple, wild apple trees, aspen, raspberry, blackberry, willow and blueberries, etc. as important cover and food species as well (Litvaitis and Tash 2006). At the Reserve, apples, common in areas previously maintained as orchards, are an important food source along with red maple (*Acer rubrum*), highbush blueberry (*Vaccinium corymbosum*), aspen (*Populus tremuloides*) and black cherry (*Prunus serotina*), common saplings in successional fields at Wells NERR.

WETLAND

Riverine habitats adjacent to Wells NERR support muskrats (*Ondatra zibethicus*), mink (*Mustela vison*) and occasionally river otters (*Lontra canadensis*). As yet, beaver (*Castor canadensis*), while present in southern Maine, are not on the Reserve, but are likely found in the watersheds of the Reserve's estuaries.

Flying squirrels are found at the Reserve. Photo James Dochtermann.

Harbor seal pup hauled out on the Little River marsh. Photo Sue Bickford.

Marine

Pinnipeds are the only marine mammals that are seen on the terrestrial portions of Wells NERR. Harbor seals (see photo) may be seen on beaches and the high marsh edge as well as in the estuaries, but the Gulf of Maine is home to twenty-two species of whales and five other species of seals, including right whales (*Eubalaena* sp.), minke whales (*Balenoptera acutorostrata*), common dolphins (*Delphinus delphinus*), bottlenosed dolphin (*Tursiops truncatus*), and gray seals (*Halichoerus grypus*). Seals use the estuary as a haul-out area, and are occasionally stranded there.

Research Overview

Deer

The abundance of white-tailed deer (*Odocoileus virginianus*) in south coastal Maine has been a concern of both natural resource managers and public health professionals. In addition to its role in the ecology of Lyme disease, deer overabundance has been linked to songbird declines in northeastern forests (DeCalesta 1994); see Chapter 12. It has been estimated that deer densities over 7.9 km^{-2} begin to show adverse effects on the vegetation community and impact bird populations, primarily those species utilizing the ground and lower shrub layers (DeCalesta 1994, Redding 1995). The most recent estimate of deer density on Wells NERR far exceed this (Rand *et al.* 2003). Rand *et al.* (2003) found that higher deer densities were correlated with higher tick densities at sites in southern Maine (Fig. 13-1). Until 2002, deer hunting was prohibited on Wells NERR because of its status as a state game sanctuary, a provision that dated back to the 1930's.

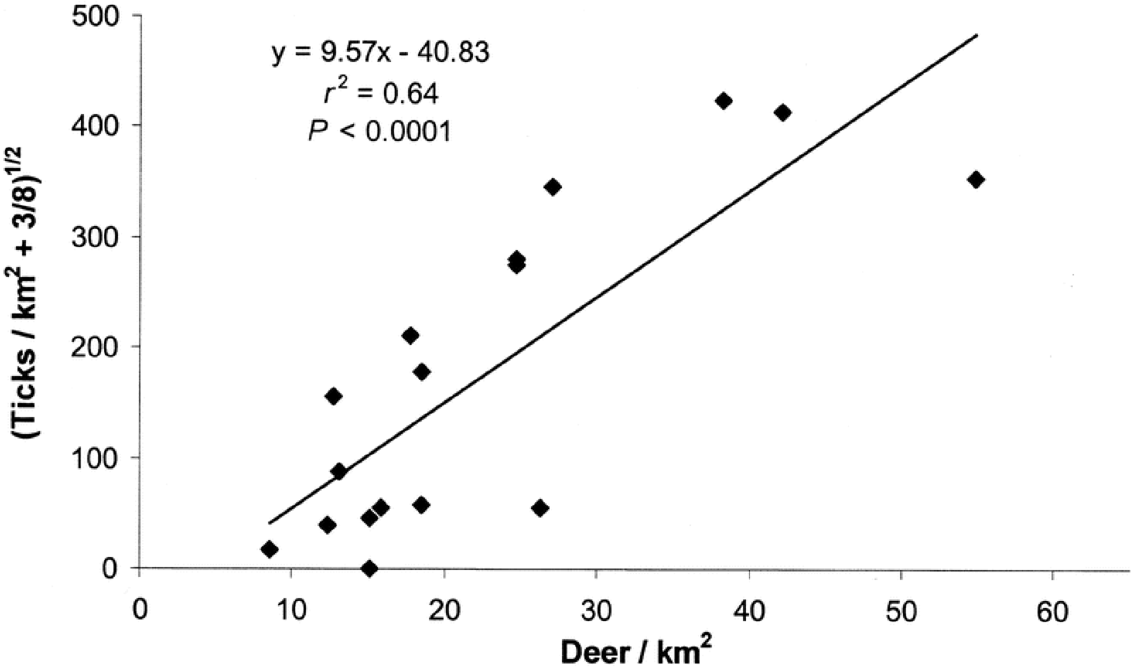


Figure 13-1: The relationship of deer km^{-2}, estimated on the basis of pellet group surveys in southern Maine, and the number of adult *I. scapularis* km^{-2} flagged from vegetation, within eight 5.2 km^2 study sites, 1998-2000 (Rand *et al.* 2003). Figure: Entomological Society of America.

A New England cottontail huddled in a thicket. Photo Ward Feurt.

Habitat Loss

In addition to being the most ecologically diverse region of Maine, south coastal Maine also contains the highest human population. Undisturbed areas are rare in this region of Maine and coastal parcels have increased in economic value, making landscape conservation much more difficult as development pressures increase.

RESEARCH NEEDS

Much more research is needed on the sustainability of New England cottontail populations. The possibility of undesirable plant species (invasive exotics) benefiting this animal might mitigate control measures on these plants (barberries, honeysuckles, etc). In addition, the role of invasive plants in providing shelter and as potential food sources is also unknown. Population dynamics of New England cottontail, including survivorship, dispersal and densities are currently unknown for the animals occurring at the Reserve. Native and exotic shrub habitat should be experimentally compared to determine their value for the cottontail and the many other native animal species that are associated with understory and successional shrub habitat.

A basic inventory of those species requiring more study at Wells NERR (chiropterans, carnivores, etc) should be implemented. Some species such as fisher (*Martes pennanti*) were historically thought to exist only in large tracts of mature forest but are thriving in southern Maine, especially in areas thought of as fragmented forest.

MANAGEMENT RECOMMENDATIONS

Wells NERR's decision in 2002 to implement a limited bow hunt to control deer in cooperation with the US Fish and Wildlife Service and the Maine Department of Inland Fisheries and Wildlife (MEDIFW) was an initial step to managing the Reserve's overabundant deer population. MEDIFW has set a target density of 15 deer mi^{-2} (≈ 8 km^{-2}) for the wildlife management zone that encompasses Wells, Maine (Lavigne 1999). This is in response, primarily, to issues of public health (Lyme disease), forest health (vegetation impacts and forest bird impacts), and residential impacts from deer that migrate from the Reserve. Although, to date, less than a hundred deer have been harvested, this process should continue with the cooperation of the stakeholders involved. Ultimately, if this approach does not produce desired results, other means of controlling deer numbers at Wells NERR should be explored.

Winter snows at Wells NERR allow many opportunities for tracking. These prints most likely belong to a Racoon. Photo Susan Bickford.

In 2006, the Wells NERR and Rachel Carson NWR formed a partnership to devise strategies for developing a shrubland management plan to improve habitat for the New England cottontail. A plan was developed that suggests blocks of connected ares where shrubland management continues, native plants are promoted, apple trees released and alder regenerated. Removal of invasive plants should continue, taking care that winter cover for the New England cottontail is not eliminated before other suitable cover is established.

Although some invasives, such as honeysuckles, could be important for cover, other species such as Asiatic bittersweet (*Celastrus orbiculatus*) may aggressively impede potential food resources such as apples. Management of bittersweet should be conducted—either through cutting, mowing, or application of herbicide in thickly infested habitats—in order to release apples and cherries. Areas which are currently not occupied by invasive plants should be kept clean, by pulling, digging or herbiciding undesirable plants to keep the problem under control. Where invasive cover is light, and there are native shrubs present, exotics should be removed. Infested areas, with documented cottontail usage, may require more research and planning to direct management actions.

Thick growth of invasive barberry may be facilitated by over-browsing of native plants by white-tailed deer. Photo Charles Lubelczyk.

For the management of the federally threatened piping plover (*Charadrius melodus*) or the State endangered least tern (*Sterna antillarum*), it is possible that on occasion predatory mammals may need to be controlled. It is recommended that this control be conducted on as-needed basis.

References

Barbour, M.S. and J.A. Litvaitis. 1993. Niche dimensions of New England cottontails in relation to habitat patch size. Oecologia 95:321-327.

DeCalesta, D.S. 1994. Effects of white-tailed deer on songbirds within managed forests in Pennsylvania. Journal of Wildlife Management. 58: 711-718.

Hawks, W.E. 1992. Do behavioral or life history characteristics of the white-footed mouse predict deer tick load? Masters thesis, University of New Hampshire Durham, NH. 28 pp.

Jones, C.G., R.S. Ostfeld, M.P. Richard, E.M. Schauber and J.O. Wolff. 1998. Chain reactions linking acorns to gypsy moth outbreaks and Lyme disease risk. Science. 279:1023-1026.

Krohn, W.B., R.B. Boone, S.A. Sader, J.A. Hepinstall, S.M. Schaefer and S.L. Painton. 1998. Maine Gap Analysis - a geographic analysis of biodiversity. Final contract report to USGS Biological Resources Division, Gap Analysis Program, Moscow, Idaho. 123 pp.

Lavigne, G.R. 1999. White-tailed deer assessment and strategic plan. Maine Dept. of Inland Fisheries and Wildlife, Bangor, ME. 111 pp.

Litvaitis, J.A. and R. Villafuerte. 1996. Factors affecting the persistence of New England cottontail metapopulations: the role of habitat management. Wildlife Society Bulletin 24:686-693.

Litvaitis, J.A. and J.P. Tash. 2006. Status, habitat features associated with remnant populations and identification of sites for restoration and translocation of New England cottontails. Final Report to U.S. Fish and Wildlife Service, 68 pp.

Litvaitis, J.A., B. Johnson, W. Jakubas and K. Morris. 2003. Distribution and habitat features associated with remnant populations of New England cottontails in Maine. Canadian Journal of Zoology 81:877-887.

McMahon, J. and J. Bernard. 1993. An ecological reserves system for Maine: benchmarks in a changing landscape. Report to 116th Maine legislature. State Planning Office, Augusta, ME. 94 pp.

Ostfeld, R.S. 2002. Ch 13 - Ecological webs involving acorns and mice: basic research and its management implications. *In* Oak forest ecosystems: ecology and management for wildlife. *Edited by* W.J. McShea and W.M. Healy. Johns Hopkins University Press, Baltimore, MD. 432 pp.

Probert, B.L. and J.A. Litvaitis. 1996. Behavioral interactions between invading and endemic lagomorphs: implications for conserving a declining species. Biological Conservation 76:289-296.

Rand, P.W., E.H. Lacombe, R.P. Smith, Jr. and J. Ficker. 1998. Participation of birds (Aves) in the emergence of Lyme disease in Southern Maine. Journal of Medical Entomol ogy 35 (3): 270-276.

Rand, P.W., C. Lubelczyk, G.R. Lavagne, S. Elias, M.S. Holman, E.H. Lacombe and R.P. Smith, Jr. 2003. Deer density and the abundance of *Ixodes scapularis* (Acari: Ixodidae). J Med Entom 40 (2): 179-184.

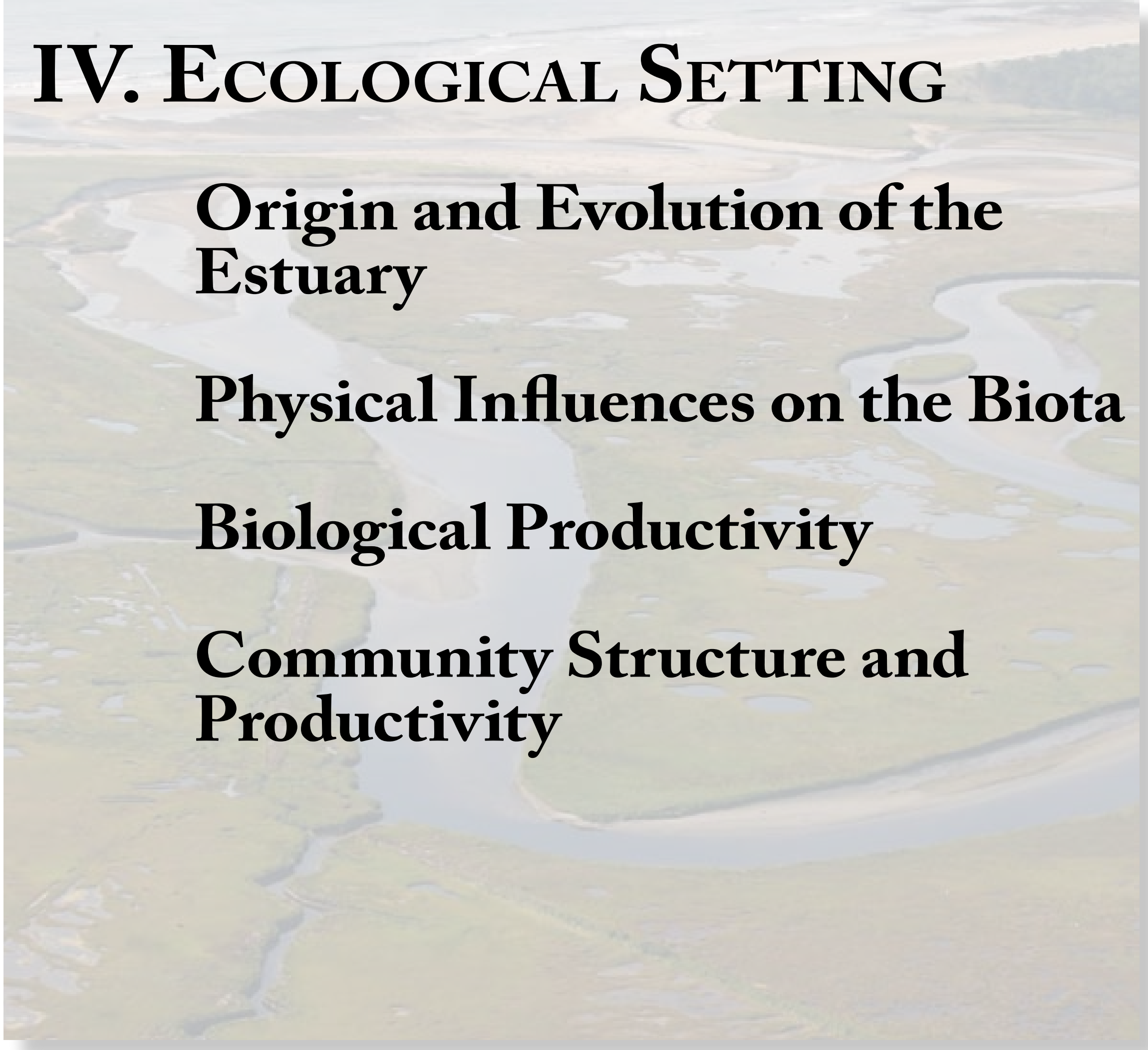
Redding, J.A. 1995. History of deer population trends and forest cutting on the Allegheny National Forest. Pages 214-224 *In* Proceedings of the 10th Northcentral Hardwoods Conference. U.S. Forest Service Technical Report NE-197. pp. 214-244.

Rich, S. 1992. A census of white-tailed deer (Odocoileus virginianus) on the Wells Reserve using night spotlighting and line transect sampling. Final Report. Wells National Estuarine Research Reserve, Wells, ME. 32 pp.

Waller, D.M. and W.S. Alverson. 1997. The white-tailed deer: a keystone herbivore. Wildlife Society Bulletin. 25(2): 217-226.

Table 13-1: Mammals found at Wells NERR.

Family	Common Name	Scientific Name
Canidae	Coyote	*Canus latrans*
	Gray Fox	*Urocyon cinereoargenteus*
	Red Fox	*Vulpes vulpes*
Cricetidae	Muskrat	*Ondatra zibethicus*
Didelphidae	Virginia Opossum	*Didelphis viginiana*
Felidae	Bobcat	*Felis rufus*
Hystricidae	Porcupine	*Erethizon dorsatum*
Leporidae	Northeast Cottontail	*Sylvilagus transitionalis*
	Eastern Cottontail	*Sylvilagus floridanus*
Mustelidae	Ermine (Short-Tailed Weasel)	*Mustela erminea*
	Fisher	*Martes pennanti*
	Masked Shrew	*Sorex cinereus*
	Mink	*Mustela sp.*
	River Otter	*Lontra canadensis*
	Striped Skunk	*Mephitis mephitis*
Phocidae	Harbor Seal	*Phoca vitulina*
Procyonidae	Raccoon	*Procyon lotor*
Rodentia	Beaver	*Castor canadensis*
	Eastern Chipmunk	*Tamias striatus*
	Gray Squirrel	*Sciurus carolinensis*
	Hairy Tailed Mole	*Parascalops breweri*
	Little Brown Bat	*Myotis lucifugus*
	Meadow Vole	*Microtus pennsylvanicus*
	Northern Flying Squirrel	*Glaucomys sabrinus*
	Red Squirrel	*Tamiasciurus hudsonicus*
	Southern Flying Squirrel	*Glavcomys volans*
	Star-Nosed Mole	*Condylura cristata*
	White-Footed Mouse	*Peromyscus leucopus*
	Woodchuck (Groundhog)	*Marmota monax*
Soricidae	Short-Tailed Shrew	*Blarina brevicauda*
Ungulata	White-Tailed Deer	*Odocoileus virginianus*
Ursidae	Black Bear	*Urus americanus*



IV. Ecological Setting

Origin and Evolution of the Estuary

Physical Influences on the Biota

Biological Productivity

Community Structure and Productivity

CHAPTER 14

Origin and Evolution of the Estuary

BRITT ARGOW

Wells NERR is located on the coast of southwestern Maine. Bedrock structure frames the Maine coast through a series of outcrops of resistant rocks that form headlands and less resistant rocks of embayments and estuaries. Long-term geological processes culminated in erosion by the vast continental ice sheets of the last glaciation circa 20,000 years ago. Glacial till, sand and gravel outwash, and glaciomarine mud produced during the retreat of these glaciers provide much of the sediments for beaches, estuaries and salt marshes of Maine. Specific locations, compositions and transport systems influence the makeup of modern coastal systems. Glaciers also affected the changes in level of the land through isostatic weighting and rebound, and sea level through global eustatic melt input. A general rise in local relative sea level from a low of –60 m (200 ft) over the past 12,500 years has resulted in changing and landward migrating coastal systems. In addition, modern processes of wind, waves and tides continue to shape relict features and build new ones. It is necessary to consider the geologic history of this region in order to better understand the present environment of Wells NERR, and to predict future evolution.

GEOLOGIC HISTORY AND BEDROCK

Geologists interpret the development of the modern coastline of northern New England through evidence in the bedrock, glacial sediments, and sediments and morphology of modern-day mountains, lakes and ocean basins. These geomorphic features and the rocks that form them can be read like the pages of a very old book. We can decipher the language of the rocks by observing the results of natural processes acting today and by applying the physical laws that govern the behavior of matter and energy. The phrases we piece together have been interpreted in light of the theory of Plate Tectonics, the idea that the surface of the earth comprises semi-rigid pieces of lithosphere (earth's outer-most layer) which move relative to one another, sliding on the plastic layer beneath. Driven by heat escaping the planet and by density differences, these plates can be pulled apart, pushed together, or can slip past one another. The movement of these plates and the forces of weathering and erosion together shape the surface of the earth.

Today, the bedrock that underlies New England is made up of "terranes," pieces of continental crust that were accreted onto the edge of the existing continental land mass in a series of convergent collisions over a period of hundreds of millions of years (Berry and Osberg 1989, Marvinney and Thompson 2000). These collisions left their mark in the form of linear mountain ranges and in the markedly complex bedrock geology that characterizes this region (Fig. 14-1; Hussey and Marvinney 2002,

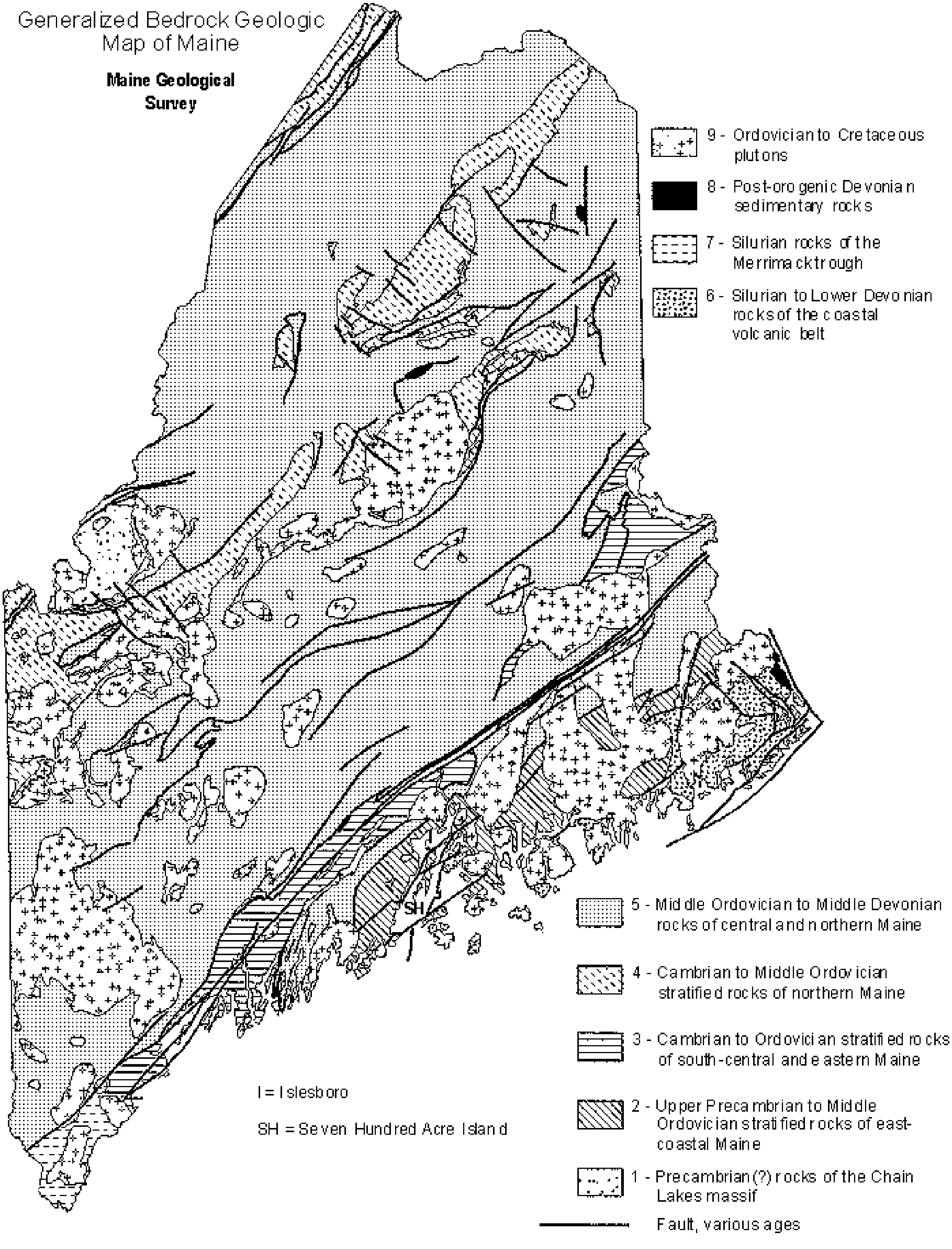


Figure 14-1: The bedrock geology of Maine. Image courtesy of the Maine Geological Survey.

Osberg *et al.* 1985). These terranes added new land to the proto-North American continent.

The geologic history of the area surrounding Wells NERR began relatively late in the development of the North American plate. About 500 million years ago, the northeastern coast of North America was a tectonically active region, prone to earthquakes and igneous activity. A volcanic island arc, similar to today's Japan, was carried across the ancestral Atlantic (Iapetus) ocean by moving lithospheric plates as if on a conveyer belt. Over the course of millions of years, these pieces of continent and intervening ocean sediments were slowly pushed onto the edge of proto-North America, deforming the rocks and causing igneous activity and earthquakes (Neuman, 1984; Ludman, 1986; Berry and Osberg, 1989; van der Pluijm *et al.* 1995). From ≈ 450 — 350 million years ago, large sedimentary basins opened and were filled with debris eroded from the uplands (Osberg *et al.* 1989; Hanson and Bradley, 1989).

These sands and muds were progressively buried, metamorphosed, and then folded and faulted as another piece of continent (Avalonia) and intervening seafloor sediments were sutured on to the North American proto-continent during the Devonian period of earth's history, circa 420—400 million years ago (Ludman, 1986; Osberg *et al.* 1989, Marvinney and Thompson, 2000). Mountains formed as the crust was deformed and faulted, and sediments were again eroded from the uplifted region and deposited in basins, eventually forming sedimentary rocks. These rocks, together with the pre-existing rocks of the area, were crumpled, folded, fractured, buried, and metamorphosed by continuing collision with a major landmass (called Gondwana) from the east around 350—300 million years ago (Hussey, 1988; Guidotti, 1989). This collision created much of the major mountain chain that runs up the east coast of North America and is still visible today. Magma formed beneath the new mountains and rose to form granites circa 300 million years ago (Tomascak *et al.* 1996, Marvinney and Thompson 2000).

At this time, the rocks that would later underlie the Wells NERR site were located near the middle of the supercontinent known as Pangea, far from any coast. Around the beginning of the Mesozoic Era (248—66 million years ago), Pangea was slowly torn apart as rifting associated with the opening of the Atlantic Ocean caused basaltic magma to rise to the surface through the fractured rocks, creating dark-colored dikes which now can be seen in the southwestern Maine, along with granites and the metamorphosed sandstones and slates of the ancient basins (McHone 1992; Swanson 1992). The spasmodic forces associated with the widening of the ocean basin caused intermittent folding, faulting and igneous activity throughout the Mesozoic and into the Cenozoic Era (66 million years ago to present). The mountains to the west continued to erode and uplift, shedding sediment onto a growing continental shelf extending into the Atlantic Ocean basin (Berry and Osberg 1989, Marvinney and Thompson 2000).

The Cenozoic Era (from 65 million years ago to the present) was characterized by shifting relative sea level over the developing continental shelf, as the underlying crust continued to flex in response to the erosion of the western mountains and the deposition of large volumes of sediment in the lowlands. This was the setting for the last major geologic events to affect the modern landscape of this area: the Pleistocene glaciations, that occurred during colder periods commonly known as the Ice Ages over the past 1.6 million years.

GLACIAL HISTORY OF NEW ENGLAND

The world entered a colder period in its history known as the Pleistocene Epoch 1.6 million years ago. Repeated glaciations and interglacials (relatively warm periods) changed the landscape of North America. Each successive glaciation obliterated most of the continental evidence for earlier events as the masses of moving ice scraped away soils and sediments, exposing and scouring away bedrock. For this reason it is the last major glacial advance, which reached it maximum extent ≈ 20,000 years ago, which is primarily responsible for the large-scale geomorphology and local surface geology of the Wells NERR region.

The last glaciation began approximately 30,000 years ago. Glaciers in the Canadian Rockies grew and coalesced as temperatures dropped and winter snowfall exceeded summer melting. A large mass of ice, known as the Laurentide Ice Sheet, formed in the region now known as

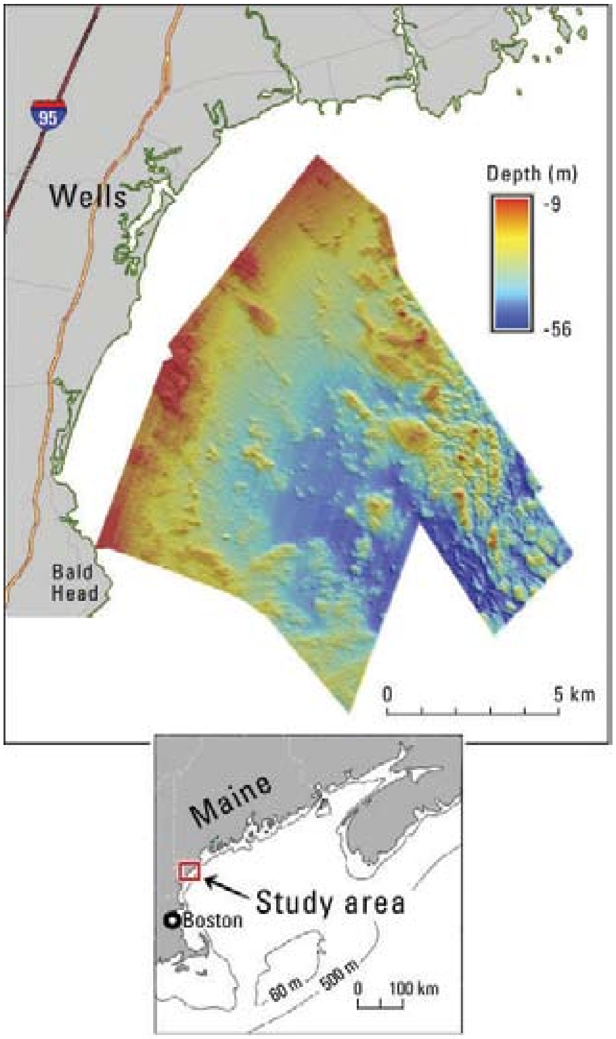


Figure 14-2: Shaded-relief bathymetric map of Wells Embayment showing features common to a glaciated continental shelf (Barnhardt 2005). Courtesy of USGS and the University of Maine.

Hudson Bay. Over time the ice built up, reaching thicknesses of several kilometers, and began to flow outward under its own weight. As the continental ice sheet moved, rocks and sediment were scraped up and incorporated into the ice. The ice flowed over the landscape like a giant power-sander, scouring and re-shaping the bedrock. The modern Gulf of Maine was created by the advance of the Laurentide Ice Sheet. At its greatest extent, the ice covered most of North America down to 40° N and extended past the present shoreline to George's Bank. The large quantities of water trapped in glacial ice worldwide caused global sea level to be almost 125 m (400 ft) lower than present levels 22,000 years ago (Fairbanks, 1989).

Around 20,000 years ago, the ice sheet stopped advancing as climate began to warm (Gibbard and van Kolschoten 2004). The ice continued to flow outward from its center in Canada, but now melting at the leading edge equaled, and then exceeded, the production of ice from snowfall at its source. Large quantities of sediment were released at the terminus of the glacier as the ice melted, forming extensive ridges called moraines. Under the melting ice, dropped sediment created an irregular topography with features such as kames, eskers and drumlins. Sediment deposited by glaciers can be recognized as a mix of rock types and particle sizes, from rock flour to giant boulders, called till. The site of Wells NERR was deglaciated circa 15,000 years ago. As the ice front melted, numerous streams and lakes were formed, sorting and redistributing some of the till into broad features called outwash plains (Smith and Hunter 1989; Weddle 1992). These glacial features, as well as exposed bedrock outcrops, characterize the Maine coastline and shape the bathymetry of the waters offshore (Figure 14-2; Smith and Hunter 1989, Kelley and Belknap 1991, Barnhardt *et al.* 1996, Kelley *et al.* 1998, Barnhardt 2005).

RELATIVE SEA-LEVEL RISE

Late Pleistocene History

The history of glaciation in Maine is tied to the history of changes in sea level at Wells NERR, and the modern processes that continue to shape the coastline. By 15,000 years ago, the leading edge of the Laurentide Ice Sheet was rapidly retreating, driven by warm sea currents and winds from the South. The floating ice shelf (Schnitker *et al.* 2001) melted away until the glacier was grounded on land over what is now southwestern coastal Maine. As the glaciers receded globally, large volumes of water were released to the ocean. Sea level rose by over 70 m (230 ft), flooding newly ice-free inland areas. The future site of Wells NERR was completely submerged from ≈ 15,000 — 13,000 years ago (Fig. 14-3; Thompson and Borns 1985). Fine particles of sediment, carried to the sea by glacier-fed streams, settled slowly to the bottom, blanketing the glacial till and exposed bedrock with a layer of bluish clay (Bloom 1963).

The lithospheric plates of the earth are not completely rigid; rather they flex and bow as weight is applied or removed. The development of an enormous Pleistocene ice sheet on the North American plate caused it to sink into the plastic layer beneath, just as placing a child on a rubber raft in a pool will cause the raft to locally depress. When the child is removed, the raft will rise back up. In this way, the lithosphere under New England began to rise back up as the mass of ice melted, in a process called isostatic rebound. The initial uplift expelled the sea from the land, shifting the coastline southeast onto the present inner shelf. The ice sheet continued to melt inland and northwards. Sands and gravels were deposited over the blue clay layer by migrating glacial streams and beach processes as the sea retreated.

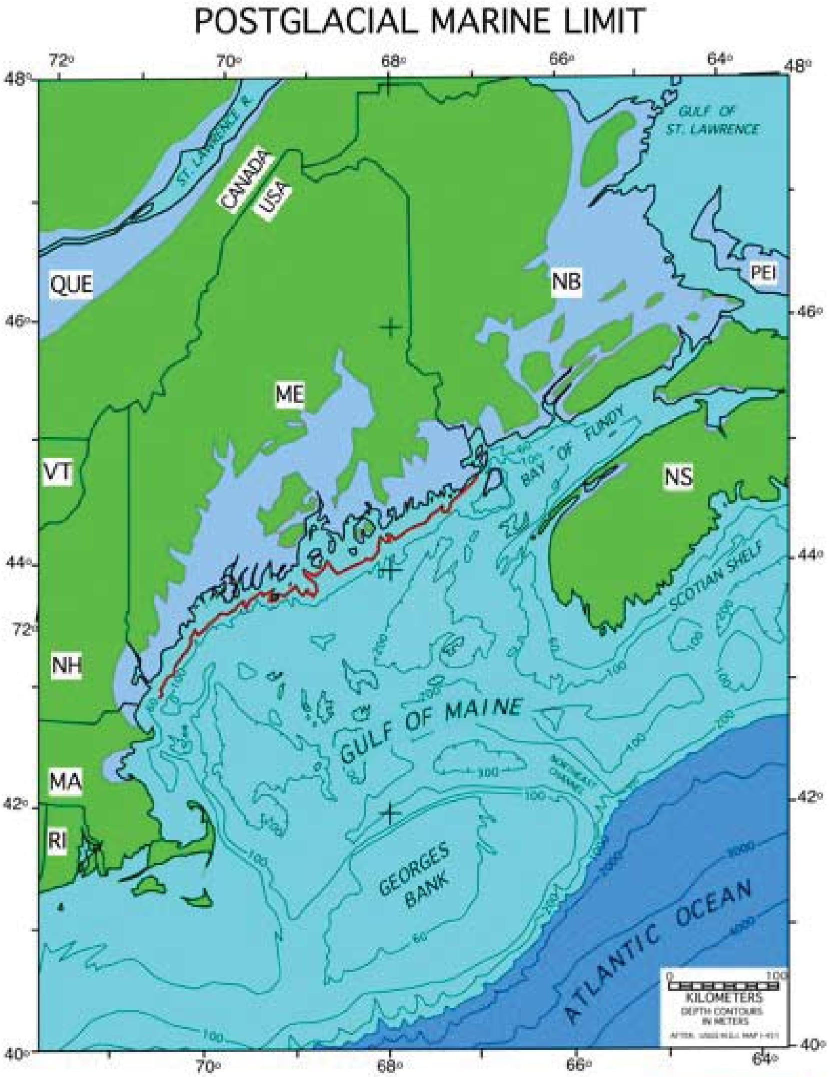
At its lowest point, or "lowstand," sea level was 60 meters below present level in the Gulf of Maine, ≈ 12,500 cal. years ago (Belknap *et al.* 1987, Barnhardt *et al.* 1997). Fast-flowing meltwater rivers cut down through the glaciomarine and till deposits on their way to the sea, carrying sands, muds and gravel to be deposited in deltas at the new shoreline over the glaciomarine clay (Belknap *et al.* 1989, 2002). Uplift slowed, and possibly temporarily reversed, as the crust adjusted to the shrinking ice sheet and a new equilibrium isostasy. This caused a relatively rapid rise in local sea level from 11,000–10,000 years ago, until uplift resumed, this time at a more gradual rate. The rising sea moved sediment, primarily sands, onshore in a migrating sand sheet or low barrier island (Montello *et al.* 1992). At this time the coastline was located between the lowstand and the present shore at a depth of approximately 20 meters below modern sea level (Barnhardt *et al.* 1995).

Holocene History

Ice continued to melt from glaciers all over earth as temperatures rose, raising global sea level at a rate roughly equal to the rate of uplift in southeastern Maine from 10,000 — 6,500 years ago (Fig. 14-4; Belknap *et al.* 2002). During this time the position of the shoreline remained relatively stable, and extensive barrier island systems developed along the coast, particularly in the shelter of arcuate embayments. Over time, barrier islands were built up by waves from reworked glacial sands deposited on the continental shelf, sediment carried to the coast by rivers, and by sediment derived from till uplands along the shoreline.

Taking a core on the Webhannet marsh. Photo Britt Argow.

By ≈ 5,000 years ago, crustal flexing in response to glacial loading had adjusted to the new mass and position oice in North America. The major ice sheets were coming closer and closer to reaching a new equilibrium with global climate, and the influx of meltwater to the oceans decreased. Even as glacial melting slowed; however, thermal expansion of sea water was increasing the volume of the oceans. Rates of global sea-level rise again exceeded rates of uplift, and the sea transgressed the shore, causing landward migration of barrier islands. Around 5,000 years ago rates of local relative sea-level rise slowed to 1.2 — 1.9 mm per year and barrier islands were established in roughly their present positions in southwestern Maine, often anchored on the rocky headlands or resistant till deposits of arcuate embayments (Hussey 1970, Jacobson 1988; Kelley *et al.* 1989). Spits prograded (i.e., grew seaward) where sediment supply from longshore movement of sediment exceeded coastal erosion. By 4,000 years ago, sea-level rise had slowed to 0.8 mm year^{-1}, and salt marshes had colonized the area behind the barrier island at Wells,



Belknap and Shipp, (1991, Fig. 1)
after: Thompson and Borns, (1985),
Rampton et al., (1984), Dyke and Prest, (1987),
Stea (1987) and Uchupi, (1965)

Maine lowstand Shoreline -
Belknap et al. 1987,
Barnhardt et al. 1997

Figure 14-3: Flooding map of Maine: light blue shows the farthest extent of post-glacial flooding of the New England coast. Map Belknap 2006, adapted from Belknap *et al.* 2005.

ME (Kelley *et al.* 1995). The presence of vegetation accelerated the infilling of the back-barrier environment. Meanwhile, rates of sea-level rise continued to slow: to 0.4 mm year^{-1} 2,000 years ago, and to just 0.2 mm year^{-1} 1,000 years ago (Kelley *et al.* 1995). Around 1,500 years ago, during this time of slow, gradual sea-level rise, the salt marshes began to build vertically and laterally, filling in the shallow open water areas behind the barrier island, until they matured into the broad supra-tidal platform we see today. Extensive research at Wells NERR (e.g. Hussey 1970, Timson and Kale 1976, Timson 1977, Nelson and Fink 1980, Kelley *et al.* 1988, Jacobson 1988, FitzGerald *et al.* 1989, Mariano 1989, Belknap *et al.* 1989, Shipp 1989, Kelley *et al.* 1995, Belknap *et al.* 2002) has led to the development of a detailed reconstruction of the geomorphic evolution of the back-barrier environment, considered next.

Evolution of the Back-Barrier Estuarine System

In order to understand the evolution of the present surface features of the Webhannet and Little River estuarine systems, scientists need to look beneath the surface at buried evidence of past landscapes. One way to do this is to collect core samples at many locations in the back-barrier and then construct a stratigraphic cross-section. A cross-section is an interpretation of the layers that exist below the surface, as if we could take a knife and slice down into the sediments like a layer cake, and take out a piece to examine. Cores are collected by forcing a hollow tube down into the sediments as far as it will go (see photo), and then withdrawing the filled tube and examining the layers inside. By plotting the relative positions of the cores and matching up similar layers, we can develop an idea of the sub-surface structure of the back-barrier. Samples of each layer are then examined to determine the environment in which that sediment was deposited, and the layers are radiometrically dated to determine the timing of deposition. From this evidence we can infer the history of Wells NERR through time.

The Webhannet River estuary formed behind a sheltering barrier island which is anchored on till and bedrock outcrops in an arcuate embayment. The embayment itself was formed as a result of the oblique intersection of the coastline with the dominant structural grain of the underlying metamorphic bedrock (Timson 1977). The resistant outcrops along this section of the coast formed headlands, and less resistant rocks eroded more deeply to form the embayment. Sediment transport by refracted waves formed the barrier spits in the shallow bays. Barrier islands developed as pre-existing barrier islands or sand bars migrated onshore with rising sea level and merged with progading spits growing from the bedrock headlands and till islands along the shore (Hussey, 1970). By ≈ 5,000 years ago, the Webhannet and Little River estuaries were established near their present geographic positions (Timson and Kale 1976; Kelley *et al.* 1995).

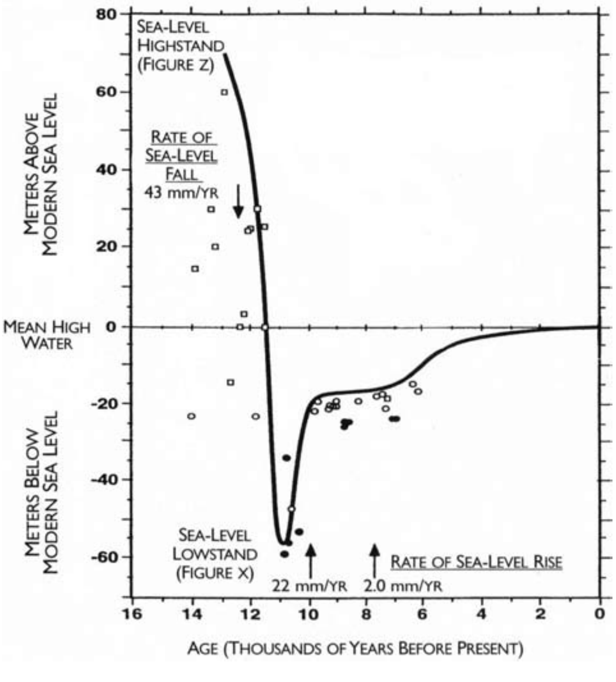


Figure 14-4: Coastal Maine historic sea level. From Journal of Coastal Research, by Kelley *et al*. 2002 Reprinted by permission of Alliance Communications Group, a division of Allen Press, Inc. © 2002 Coastal Education and Research Foundation.

The back-barrier at this time comprised reaches of shallow open water, containing some fringing salt marsh (supratidal salt marsh, or high marsh, dominated by the halophyte salt marsh hay [*Spartina patens*]). By ≈ 4,000 years ago, tidal flats incised by channels dominated the estuary. Intertidal salt marsh (low marsh, dominated by the halophyte salt marsh cordgrass [*Spartina alterniflora*]) had colonized shallow areas of the flats, especially along the landward edge of the barrier island, developing muddy peat. Salt marshes change the dynamics of the intertidal areas they invade, increasing the elevation of the land surface by trapping sediment brought by tidal waters, and through biogenic productivity (ie. partially decomposed roots and leaf matter are also trapped and help to build up the peat). Along the landward margin of the estuary, supratidal salt marsh had developed on top of the glaciomarine sediments where rising sea level drowned the upland fringe. Freshwater marsh probably existed at the heads of tributaries draining into the estuary.

Salt marsh plants are able to colonize shallow intertidal areas as long as wave energy is not too great. The shelter of the barrier island created a quiet backwater in which these grasses began to spread rapidly. Intertidal marsh species had successfully colonized most of the tidal flats in the Webhannet estuary by 3,000 years ago. Smooth cordgrass is extremely bioproductive, but primarily creates colonizing margins by trapping inorganic sediment through baffling and adhesion, leading to an increase in elevation of the marsh surface that may eventually be a colonization site for high marsh. In addition, the rising tides allowed supratidal marsh species to invade the adjacent upland margin, and the marshes grew laterally as well as vertically. Freshwater marshes were converted to salt marsh as rising sea level increased the salinity of

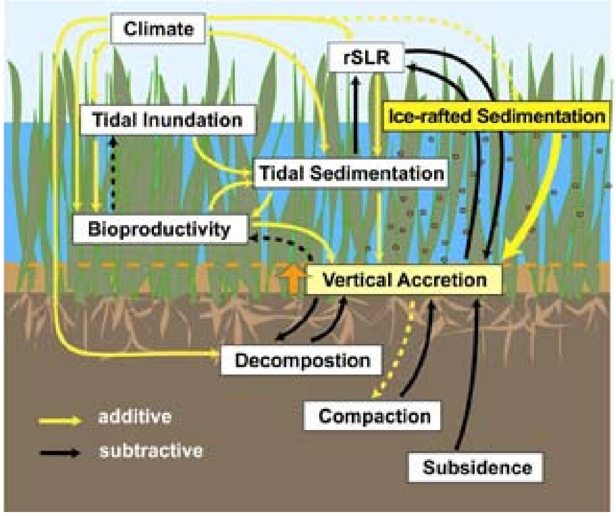


Figure 14-8: Summary of marsh sedimentation processes. Figure Britt Argow.

upstream areas. Low marsh was gradually replaced by supratidal marsh as rates of sea-level rise slowed to 0.5 mm year^{-1} 2000 years ago. By this time the tidal flats had been largely replaced by salt marsh and the basic pattern of tidal creeks present today stabilized. Low till islands had been covered by rising sea level and colonized by marsh. Supratidal high marsh formed a flat platform filling much of the back-barrier, and tidal creeks grew progressively more narrow as low marsh colonized and then built up the banks (Kelley *et al*. 1995).

The Little River estuary has a parallel late Holocene (the Holocene is ~ 10,000 years ago to the present) history. This small estuary was formed as rising sea level flooded the stream valley previously incised into the glacial sediments during the Holocene lowstand. Small barrier spits had formed fronting the estuary by ≈ 5,000 years ago. At 4,000 years before present time, intertidal salt marsh had successfully colonized the estuary. Tidal channels were stabilized by the spread of vegetation and the presence of the glaciomarine blue clay, which was difficult to erode. Sea level continued to slowly rise, but by 2,000 years ago the vertical growth of the intertidal marsh had outpaced the rising waters, and a supratidal marsh began to develop over the existing marsh and the slowly inundating upland.

Approximately 1,000 years ago, sea level was rising at a rate of only 0.2 mm per year, or 2 cm per century. The supratidal salt marsh was well-developed and filled the estuary. Tidal creeks became narrower in response to the infilling, as less water moved in and out of the estuary with each tidal cycle. Smooth cordgrass flourished, developing peat in zones along creek banks and contributing to the narrowing process. Freshwater marsh could only be found at the headwaters of small tributaries above the elevation of highest high tide. Recently, however, the pattern of estuarine evolution changed as a result of local and global human influences.

Based on the age of buried salt marsh peat and the distribution of microscopic animals like foraminifera, late Holocene sea-level rise was extremely gradual in New England until the past 1-3 centuries. Tide-gauge records from Portland, ME (Fig. 14-5), Portsmouth, NH, and Boston, MA all show that sea level is now rising at much higher rates, from 2.0—2.7 mm each year (or 20-27 cm per century), and data from Wells and other Maine marshes reflect these recent accelerations (Gehrels 2000; Gehrels *et al*. 2002). This increase in rates of sea-level rise reflects the recent global warming trend, and has affected the evolution of the estuaries of the Wells NERR (Fig. 14-6).

The barrier beach protecting the estuary of Wells NERR has been, and continues to be, shaped by coastal processes, including wind and wave action. The oblique angle of wave approach changes with the seasons. Most of the year, mild wind-driven waves approach the beach from the southeast, and gradually move sediment along the shore in a northerly direction. These low-energy waves move sediment up the beach face, widening the beaches over the summer months. Large winter "Northeaster" (see footnote Ch. 3) storms approach the shore from the northeast; however, creating high-energy waves that push large amounts of sediment southward and offshore, often effecting dramatic change in one event (Nelson and Fink 1980). Some of the sediment moved offshore is deposited in front of the inlet, where waves push it into the back-barrier environment over time. Some of this sediment is suspended and is carried onto the surface of the marsh by flood tidal currents, where it is deposited and helps to increase the elevation of the marsh surface. Other sediment, primarily sand, is too large to be suspended in the relatively quiet waters of the estuary. This sand piles up and creates shoals in the inlet and tidal channels, gradually continuing the Holocene trend of filling in the estuary

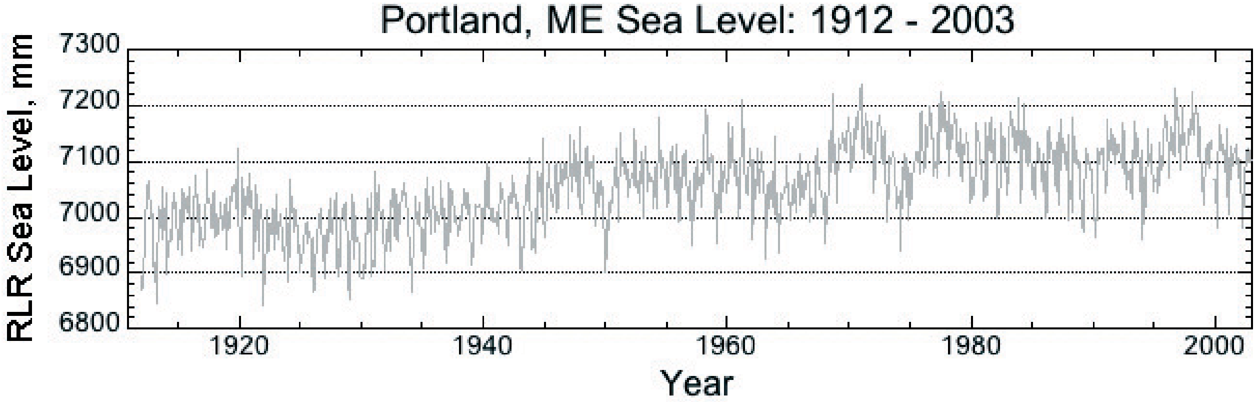


Figure 14-5: Sea level at Portland, Maine, 1912-2003. Data NOAA. Figure Hannah Wilhelm.

(Montello *et al*. 1992). These processes have contributed to changes in the configuration of the Webhannet and Little River estuaries over time, and continue to shape the back-barrier environment today.

A study of historical maps (Jacobson 1988) reveals how the Webhannet River estuary has changed since European colonization of New England. From 1774 to 1872, the channel of the Webhannet River and tidal creeks in the salt marsh seem to have eroded and widened, becoming more sinuous. In the 1920's, the heavy development of Wells Beach had necessitated barrier stabilization (eg. seawalls). This reduced the sediment available to the salt marsh and estuary. By 1956, the marsh had further eroded as tidal channels widened and the inlet to the Atlantic had widened, shallowed and migrated slightly to the south (Jacobson, 1988, Rits, 2003).

In the 1960's, the tidal inlet and parts of the Webhannet River channel were dredged and stabilized for navigation purposes. A large upland area was created by the deposition of the spoils pile on top of the marsh peats near the inlet. This changed the hypsometry of the back-barrier region, thus altering the hydrodynamics and forcing changes in the configuration of the environment. Salt marsh eroded in the northern end of the estuary. Depression of the peat under the spoils pile caused migration of nearby tidal creeks. Based on aerial photos, the back-barrier estuary adjusted rapidly (within 10 years) to the changes caused by the building of the harbor and jetties (Jacobson, 1988); however, long-term effects on vegetation and tidal channel morphology are likely due to the reduction in ocean sediment influx.

In contrast, the shoreface, barrier beaches, and ebb and flood tidal deltas experienced extensive reconfiguration in response to the harbor construction and inlet stabilization project (Byrne and Ziegler 1977, Rits 2003). Rapid shoaling made the harbor construction unexpectedly challenging, and several modifications to the original plans were required. The natural recurved spits that had flanked the inlet prior to construction rapidly filled in seaward, with the result that the barrier widened directly north and south of the jetties due to the trapping of sand formerly moved into the inlet by longshore sediment transport. Away from the jetties, thinning occurred on the Drakes Island and Wells barrier beaches due to the disruption in sediment circulation cells. By 1974 the system appeared to reach a new equilibrium with the altered inlet, and the pace of morphologic change slowed (Rits 2003).

When modern photography is compared with aerial photos from 1984, some back-barrier channel migration is observed. The main channel of the Webhannet has migrated closer to the barrier island, leading to marsh erosion and channel widening. This is most likely due to the lack of overwash deposition (a process wherein storm waves overtop the barrier island and transport sand to the landward margin of the barrier) on the stabilized and highly developed Wells Beach (Jacobson 1988). Some marsh erosion has also been observed at the seaward edge of the western marsh platform, especially near the tidal inlet (Marvinney and Thompson 2000). These changes and others will need to be carefully monitored and assessed if we are to understand, and ultimately predict, how modern environments in the Wells NERR function and evolve.

Projected Sea Level Rise

Human impacts to the Webhannet River estuary may prove to have unanticipated consequences in the future, particularly in light of the projected increase in rates of sea-level rise (Church *et al.* 2001). The latest report of the Intergovernmental Panel on Climate Change (IPCC) predicts that based on global warming and other factors, future sea levels may increase from 25-90 cm (10-30 in) over the coming century (Fig. 14-7; Church *et al.* 2001). If the historical trend continues (at the low end of predicted rates), then the historical change observed at the Wells NERR may accurately forecast change to come. Over the last 10,000 years, sea level has risen about 20 m (65 ft); therefore Holocene records preserved in salt marsh peats would also be helpful in predicting the response of coastal wetlands to rising sea level at this gradual rate. If, however, future sea-level rise exceeds this rate, as seems increasingly likely given new climate indicators (Fig. 14-6), then predictive tools such as numerical modeling and GIS technologies will be needed.

During the past 5,000 years, sea level has risen at an extremely gradual average rate of less than 10 cm per century, 5 m total. However, over the past century, tide gauge data indicates that recent sea level rise has been over twice as fast: 27 cm (11 in) per century in southwestern Maine. What are the causes of sea-level rise, and what other changes can we expect from this phenomenon? Most coastal salt marshes that have not been altered by development are currently keeping pace with rising regional sea level. If, however, coasts undergo accelerated sea-level rise, then questions arise: can New England salt marshes maintain their areal extent through vertical accretion and shoreward transgression? What is the functional limit of vertical accretion annually? If salt marshes cannot accrete at rates comparable to accelerated sea-level rise, then at what critical point, or threshold, will they become inundated with marine waters? If marshes submerge, what happens to the surrounding estuarine environment?

The potential loss of coastal wetlands is an important issue for several reasons. Coastal wetlands like the salt marshes of Wells NERR are among the most productive ecosystems on earth, serving as nursery grounds for many oceanic species and supplying detritus and living biomass to the waters offshore, which forms the basis of the open-ocean food web. Marshes filter pollutants and particulates from surface waters before they reach the oceans (Mitsch and Gosselink 1986, Kennish 2001, Adam 2002). The dense stands of vegetation act as buffer zones for inland areas, absorbing storm energies and storing flood waters. The loss of this protection presents an unmistakable hazard to human coastal development. Finally, marshes are characterized by a flat topographic profile, and often cover a sizable area. As the marsh is flooded, a significant volume of water is added to the tidal prism. This increase in tidal prism can potentially lead to dramatic shoreline erosion as higher tidal velocities scour a larger tidal inlet, and to significant increases in sand sequestered in the ebb tidal delta (Fig. 14-7; List *et al.* 1994, FitzGerald *et al.* 2006). Clearly, this has important implications for coastal communities, resource management, and hazards assessment.

Conceptual Model

Stable Barrier

Field investigations of marsh accretion rates suggest that marshes are relatively stable and compatible with the present trend of eustatic sea-level rise. Therefore, the present general configuration of mixed energy coasts, such as that along which Wells NERR is found, is used as the initial phase in the conceptual model. This morphology is represented by a barrier chain backed by an expansive high tide or supratidal marsh that is cut by a network of tidal creeks. Inlets along mixed energy coasts are fronted by well-developed ebb-tidal deltas, although their intertidal exposure varies greatly depending upon tidal range, inner shelf slope, wave energy, and other factors (Smith and FitzGerald 1994).

Marsh Decline

Stage 1 of the model represents a period when the rate of sea-level rise has accelerated, transforming portions of the supratidal and high tide marsh to intertidal and subtidal environments. The resulting increase in tidal discharge strengthens tidal flow at the inlet, leading to scouring of tidal creeks and enlargement of the main inlet channel. Increasing tidal prism causes a growth in the equi-

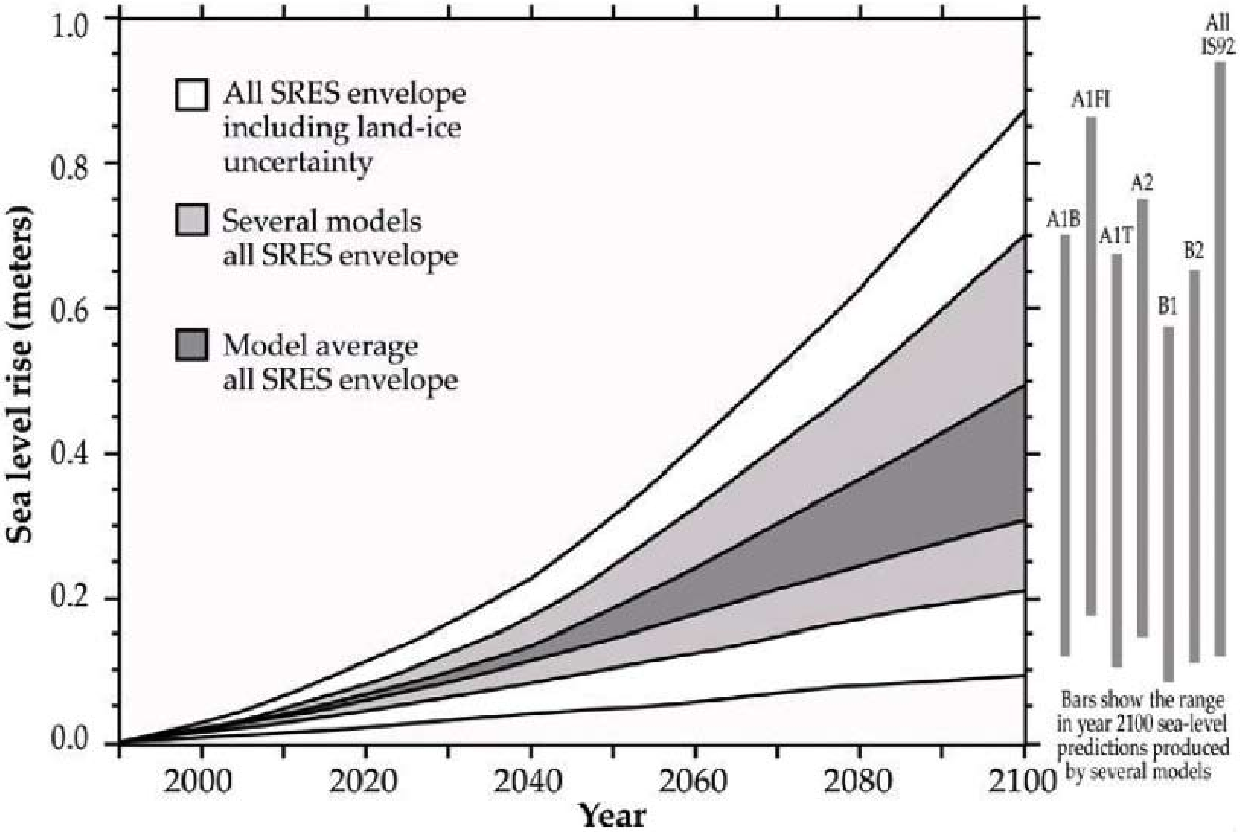


Figure 14-6: Sea level rise hypotheses from the International Panel on Climate Change. Source Argow 2007, modified from Church *et al*. 2001.

librium volume of the ebb-tidal delta. The expansion of open water landward of the inlet creates accommodation space, leading to the formation of new flood-tidal deltas and to the growth of existing deltas. Sand sequestered on the ebb-tidal delta is sourced partially from sediment eroded in back-barrier tidal creeks and at the inlets, as these channels enlarge in response to increasing tidal flow. However, most of the sediment transferred to the ebb-tidal delta is captured from sand transported to the inlet via the longshore transport system. The rate of sand trapping on the ebb-tidal delta dictates the extent and rate of downdrift shoreline erosion.

Fringing Marsh and Marsh Islands

By *Stage 2* most of the marsh has not kept pace with rising sea level. Extensive wetlands have been overtopped by rising sea level and converted to open water and intertidal regions. In addition, encroaching tidal waters are flooding portions of the mainland. Subtidal and intertidal environments comprise most of the back-barrier. Increasing tidal prism continues to enlarge the size of the tidal inlets and the volume of the ebb-tidal deltas. Changes in the dimensions of the inlet channel combined with alterations in back-barrier hypsometry have produced a tidal regime favoring flood tidal current dominance and the landward transport of sand. As the back-barrier is transformed from a partially filled basin to an open water basin having a deep communication to the ocean, the hydraulics of the inlet change from one dominated by ebb currents and natural sand flushing abilities to an inlet dominated by flood tidal currents and landward bedload transport (Mota Oliveira 1970; Boon 1981; Aubrey and Speer 1985). Thus, during this stage flood-tidal deltas and other back-barrier shoals grow in size as sand is siphoned from the littoral system, further depleting sand nourishment to adjacent barrier shorelines. At the end of *Stage 2*, thinning barriers are occasionally breached and ephemeral and permanent tidal inlets are formed.

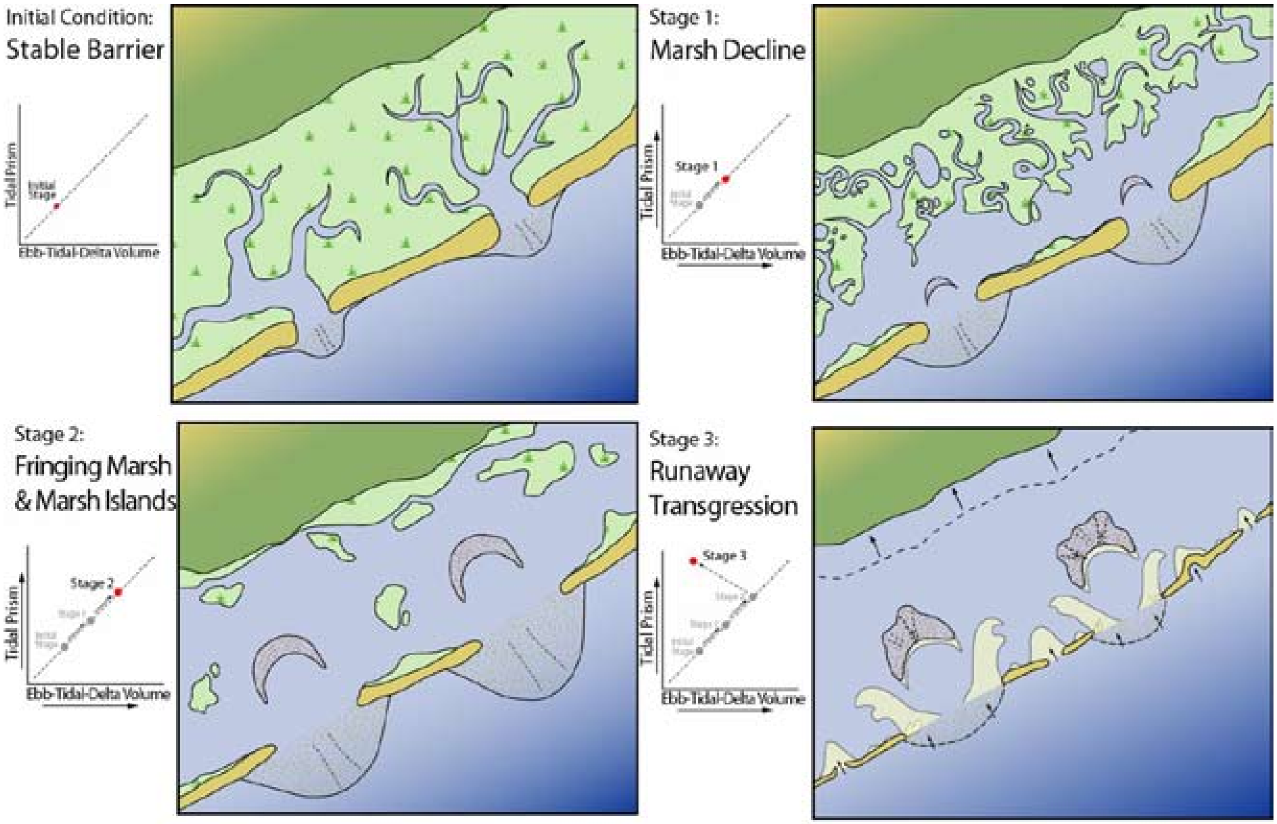


Figure 14-7: Conceptual model of effects of sea-level rise on estuary (Argow 2007; also appears in Fitzgerald *et al.* 2006).

Runaway Transgression

Stage 3 occurs after the barriers have become largely sediment-starved. Many new tidal inlets have developed, and barrier rollover is an active process during moderate to large storms. During barrier rollover, high-energy waves move sand from the nearshore zone in front of the barrier up and over the island, knocking down dunes and redistributing sand into the back-barrier. This process, over time, moves the barrier island closer to the mainland shore. Sand shoals and vestiges of marsh act as stabilization points where the retrograding barrier may become re-established. During this time multiple new tidal inlets along the barrier chain effectively reduce tidal prisms at many of the former large inlets, causing the collapse of their ebb-tidal deltas onshore. The reduction in volume of the ebb deltas provides a temporary source of sand for the ephemeral barriers. The ultimate fate of the barriers and their re-establishment onshore is dependent on the trend of sea-level rise.

So, what is the current state of the salt marshes at the Wells NERR? In the Webhannet estuary, some sediment is still being transported into the jettied inlet (leading to recurring shoaling and dredging, most recently in 2000), but it is a fraction of the pre-modification sediment influx, and it is unclear whether it is sufficient to maintain the vertical elevation of the marsh platform against rising sea level. On-going research at Wells NERR seeks to discover and quantify all inputs of inorganic sediment to the marsh surface (Argow *et al.* 2006) and to assess the current distribution and bioproductivity of salt marsh species (Burdick and Moore, in prep., Konisky 2003) Seasonal sedimentation processes such as ice rafting (Wood *et al.* 1989, Kelley *et al.* 1995, Argow 2007) are an additional source of inorganic sediment to the marsh surface in this cold-temperate region, helping the marsh to keep pace with rising sea level. Changing vegetation patterns on the marsh may serve as an early indicator of the marsh's response to current sea level change, well before a measurable change in sediment dynamics or hydrology occurs. Historic morphological changes such as increased marsh pool development (Wilson 2006), tidal creek widening or migration, and changes in the surface elevation due to compaction, sedimentation or bioproductivity must all be monitored to increase our understanding of the changing estuarine environment. Ultimately the scientific community will need to draw on many lines of investigation in order to be prepared to support sensible and responsible management action in the uncertain future.

REFERENCES

Adam, P., 2002. Saltmarshes in a time of change. Environmental Conservation, 29(1): 39-61.

Aubrey, D.G. and Speer, P.E., 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems Part I: Observations. Estuarine, Coastal and Shelf Science, 21(2):185-205.

Argow, B.A. 2006. Winter processes on New England salt marshes. Dissertation, Boston University, Boston, MA. 379 pp.

Barnhardt, W.A., Gehrels, W.R., Belknap, D.F. and Kelley, J.T., 1995, Late Quaternary relative sea-level change in the western Gulf of Maine: evidence for a migrating glacial forebulge: Geology, v. 23, p. 317-320.

Barnhardt, W.A. 2005. New equipment deployed to map sea-floor geology in southern Maine. *In* Soundwaves, United States Geological Survey. Available from http://soundwaves.usgs.gov/2005/11/. [Accessed 21 December 2006.]

Barnhardt, W.A., Belknap, D.F., and Kelley, J.T., 1997, Sequence stratigraphy of submerged river-mouth deposits in the northwestern Gulf of Maine: responses to relative sea-level changes. Geological Society of America Bulletin, v. 109, p. 612-630.

Barnhardt, W.A., Kelley, J.T., Belknap, D.F., Dickson, S.M., and Kelley, A.R., 1996, Surficial geology of the inner continental shelf of the northwestern Gulf of Maine: Piscataqua River to Biddeford Pool. Maine Geological Survey Geologic Map 96-6, 1:100,000 (one of seven maps in an atlas of the coast of Maine).

Belknap, Daniel F., 1987, Presumpscot Formation submerged on the Maine inner shelf, in Andrews, David W., Thompson, Woodrow B., Sandford, Thomas C., and Novak, Irwin D., *editors*, Geologic and geotechnical characteristics of the Presumpscot Formation, Maine's glaciomarine 'clay': unpublished proceedings of a symposium sponsored by the Maine Geological Survey, Morrison Geotechnical Engineering, University of Maine, and University of Southern Maine, March 20, 1987, variously paginated 10 pp.

Belknap, D.F., R.C. Shipp, R. Stuckenrath, J.T. Kelley, and H.W. Borns, Jr. 1989. Holocene sea-level change in coastal Maine. *In* Neotectonics of Maine. *Edited by* Anderson, W.A. and H.W Borns, Jr. Maine Geological Survey Bulletin No. 40 pp. 85-106.

Belknap, D.F., J.T. Kelley, and A.M. Gontz, 2002. Evolution of the glaciated shelf and coastline of the northern Gulf of Maine, USA. Journal of Coastal Research, Special Issue 36, 37-55.

Belknap, D.F., A. M. Gontz, and J.T. Kelley, 2005. Calibrating and updating the Maine relative sea-level curve in a search for regional variations in crustal responses. Geological Society of America Abstracts with Programs 37(1): 6.

Berry, H. N., and P.H.Osberg, 1989, A stratigraphic synthesis of eastern Maine and western New Brunswick. *In* Studies in Maine geology: Volume 2 - structure and stratigraphy: *Edited by* Tucker, R. D., and R.G. Marvinney. Maine Geological Survey, pp. 1-32.

Bloom, A.L., 1963. Late Pleistocene fluctuations of sea level and postglacial crustal rebound in coastal Maine. American Journal of Science, 261: 862-879.

Boon, J.D., III and Byrne, R.J., 1981. On basin hypsometry and the morphodynamic response of coastal inlet systems. Marine Geology, 40: 27-48.

Byrne, R.J. and J. Ziegler, J., 1977. Coastal engineering study, Wells Harbor, Maine. Waltham, MA: US Army Corps of Engineers, New England Division, p.89.

Church, J.A., J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M.T. Nhuan, D. Qin, and P.L Woodworth. 2001. Changes in Sea Level. *In* Climate Change 2001: The Scientific basis: contribution of working group I to the third assessment report of the intergovernmental panel on climate change. *Edited by* Houghton, Y.D. J. T., D.J. Griggs, M. Noguer, P. J. van der Linden and D. Xiaosu. Cambridge University Press. pp. 638-689.

Fairbanks,R. G. 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342: 637–642.

FitzGerald, D.M., J.M. Lincoln, L.K. Fink, and D.W. Caldwell. 1989. Morphodynamics of tidal inlet systems in Maine. *In* Studies in Maine geology: Volume 5 – quaternary geology *Edited by* Tucker, R. D., R.G. Marvinney, Maine Geological Survey, Augusta, ME, pp. 67-96.

FitzGerald, D.M., I.V. Buynevich, B.A. Argow. 2006. Model of tidal inlet and barrier island dynamics in a regime of accelerated sea-level rise. Journal of Coastal Research Special Issue 39: 789-795.

Gehrels, W.R., D.F. Belknap, S. Black, and R.M. Newnham. 2002. Rapid Sea-level rise in the Gulf of Maine, USA, since AD1800. The Holocene 12: 383-389.

Gehrels, W.R. 2000. Using foraminiferal transfer functions to produce high-resolution sea-level records from salt-marsh deposits, Maine, USA. The Holocene 10: 367-376.

Gibbard, P. and T. van Kolfschoten. 2004. The Pleistocene and Holocene epochs, *In* A geologic time scale 2004. *Edited by* Gradstein. F.M., J.G. Ogg, and A.G. Smith. Cambridge University Press, Cambridge, U.K. 610 pp.

Guidotti, C. V., 1989, Metamorphism in Maine: an overview. *In* Studies in Maine geology: Volume 3 - igneous and metamorphic geology: *Edited by* Tucker, R. D. and R.G. Marvinney, R. G., Maine Geological Survey, p. 1-17.

Hanson, L. S., and Bradley, D. C., 1989, Sedimentary facies and tectonic interpretation of the Lower Devonian Carrabassett Formation, north-central Maine, *In* Studies in Maine geology: Volume 2 - structure and stratigraphy *Edited by* Tucker, R. D. and R.G. Marvinney. Maine Geological Survey, p. 101-126.

Hussey, A.M., 1970. Observations on the origin and development of the Wells Beach area, Maine. Maine Geological Survey Bulletin, 23, 58-68.

Hussey, A. M.1988, Lithotectonic stratigraphy, deformation, plutonism, and metamorphism, greater Casco Bay region, southwestern Maine, *In* Studies in Maine geology: Volume 1 - structure and stratigraphy *Edited by* Tucker, R. D. and R.G. Marvinney, Maine Geological Survey, p.17-34.

Hussey, Arthur M., II and Marvinney, Robert G., 2002, Bedrock geology of the Bath 1:100,000 quadrangle, Maine, Maine Geological Survey (Department of Conservation), Open-File Map 02-152, scale 1:100000 Jacobson, H., 1988. Historical development of the salt marsh at Wells, Maine. Earth Surface Processes and Landforms, 13: 475-486.

Jacobson, H., 1988. Historical development of the salt marsh at Wells, Maine. Earth Surface Processes and Landforms, 13: 475-486.

Kelley, J.T., Belknap, D.F., Jacobson, G.L. and Jacobson, H.A., 1988. The Morphology and Origin of Salt Marshes Along the Glaciated Coastline of Maine, USA. Journal of Coastal Research, 4(4): 649-666.

Kelley, J.T., R.C. Shipp, and D.B. Belknap. 1989. Geomorphology and late quaternary evolution of the Saco Bay region, Maine coast. *In* Studies in Maine geology: Volume 5 – quaternary geology *Edited by* Tucker, R. D., and R.G. Marvinney pp. 47-66. Maine Geological Survey,

Kelley, J. T., and Belknap, D. F. 1991. Physiography, surficial sediments and Quaternary stratigraphy of the inner continental shelf and nearshore region of the Gulf of Maine. Continental Shelf Research, v. 11, p. 1265-1283.

Kelley, J.T., W.A. Barnhardt, D.F. Belknap, S.M. Dickson, and A.R. Kelley. 1998. The seafloor revealed: The geology of Maine's inner continental shelf. A report to the Regional Marine Research Program, Maine Geological Survey Open-File Report 98-6. 55 pp. Available from http://www.state.me.us/doc/nrimc/pubedinf/pubs/plcoast.htm [Accessed 21 November 2006]

Kelley, J.T., R.W. Gehrels, and D.F. Belknap. 1995, Late Holocene relative sea-level rise and the geological development of tidal marshes at Wells, ME, U.S.A. Journal of Coastal Research, 11(1): 136-153.

Kennish, M.J., 2001. Coastal salt marsh systems in the US: A review of anthropogenic impacts. Journal of Coastal Research, 17(3): 731-748.

List, J.H., B.E. Jaffe, A.H. Sallenger Jr., S.J. Williams et al. 1994. Louisiana Barrier Island Erosion Study: Atlas of Sea-floor Changes from 1878 to 1989. US Geological Survey Miscellaneous Investigations Series,

Ludman, A., 1986, Timing of terrane accretion in eastern and east-central Maine: Geology, v. 14, p. 411-414. McHone, J. G., 1992, Mafic dike suites within Mesozoic igneous provinces of New England and Atlantic Canada, In Eastern North American Mesozoic magmatism: *Edited by* Puffer, J. H., and Ragland, P. C. Geological Society of America Special Paper 268. pp. 1-12.

Neuman, R. B., 1984, Geology and paleobiology of islands in the Ordovician Iapetus Ocean: review and implications: Geological Society of America, Bulletin, 95: 1188-1201.

Mariano, C. G., 1989. Wave-current interaction at Wells Inlet and a comparison of hydraulics and sand circulation with Little River Inlet. Masters thesis, Boston University, Boston, MA. 190 pp.

Marvinney, R. G., and Thompson, W. B., 2000, A geologic history of Maine. *In* Mineralogy of Maine: volume 2 - Mining history, gems, and geology. *Edited by* King, V. T. Maine Geological Survey. pp. 1-8.

Mitsch, W.J. and Gosselink, J.G., 1986. Wetlands. Van Nostrand Reinhold Company, New York, 539 pp.

Montello, T.M., D.M. FitzGerald, S. van Heteren, D.W. Caldwell, L.K. Fink, Jr., 1992. Stratigraphy and evolution of the barrier system along the Wells-Ogunquit Embayment in southern Maine. Technical Report No. 15.

Mota Oliviera, I.B., 1970. Natural flushing ability in tidal inlets, 12th Coastal Engineering Conference. American Society of Civil Engineers, Washington D.C., pp. 1827-1845.

Nelson, B.W., and L.K. Fink. 1980. Geological and botanical features of sand beach systems in Maine. Planning Report No. 54. Maine Critical Areas Program Maine State Planning Office, Augusta, ME 169 pp.

Osberg, P. H., A.M. Hussey, II, and G.M. Boone. 1985, Bedrock geologic map of Maine: Maine Geological Survey

Osberg, P. H., J.F. Tull, P. Robinson, R. Hon, and J.R. Butler. 1989, The Acadian orogen, *In* The Appalachian-Ouachita orogen in the United States *Edited by* R.D. Hatcher, Jr., W.A. Thomas, G.W. Viele. Geological Society of America, The Geology of North America, v. F-2, p. 179-232.

Rits, Mark, 2003. Wave-current interaction, sediment transport, and the responses of a jettied channel to dredging, Wells, Inlet, Maine. Masters thesis, Boston University, Boston MA 325 pp.

Schnitker, Detmar, Batchelor, Barbara, and Belknap, Daniel F., 1991, The end of glacial conditions in the Gulf of Maine (abstract), Geological Society of America, Northeastern Section, 26th Annual Meeting, Abstracts with Programs, v. 23, no. 1, p. 124

Smith, G. W., and Hunter, L. E., 1989, Late Wisconsinan deglaciation of coastal Maine, *In* Studies in Maine geology; Volume 6 - Quaternary geology. *Edited by* Tucker, R. D., and R. G. Marvinney. Maine Geological Survey, p. 13-32.

Smith, J.B. and FitzGerald, D.M., 1994. Sediment transport patterns at the Essex River Inlet ebbtidal delta, Massachusetts, U.S.A. Journal of Coastal Research, 10: 752-774.

Shipp, R.C., 1989. Quaternary stratigraphy of the inner continental shelf and adjacent coastal region of Maine. Dissertation, University of Maine, Orono, Maine, 832 pp.

Swanson, M. T., 1992, Structural sequence and tectonic significance of Mesozoic dikes in southern coastal Maine, *In* Eastern North American Mesozoic magmatism *Edited by* J.H. Puffer, and P.C. Ragland. Geological Society of America, Special Paper 268, pp. 37-62.

Tomascak, P. B., E.J. Krogstad, R.J. Walker. 1996, U-Pb monazite geochronology of granitic rocks from Maine: implications for late Paleozoic tectonics in the northern Appalachians: Journal of Geology 104: 185-195.

Thompson W.B., H.W. Borns, Jr., 1985. Surficial geologic map of Maine. Maine Geological Survey, Augusta ME.

Timson, B.S., 1977, A Handbook of Coastal Marine Geological Environments of the Maine Coast, Maine State Planning Office, Augusta, ME.

Timson, B.S., and Kale, D., 1976, Historical changes of the Webhannet River Inlet, Report to the New England Division, U.S. Army, Corps, of Engineers.

van der Pluijm, B., A.R. van der Voo, and T. H. Torsvik, 1995. Convergence and subduction at the Ordovician margin of Laurentia, *In* Current perspectives in the Appalachian-Caledonian orogeny. *Edited by* Hibbard, J. P., C. R van Staal, and P. A. Cawood. Geological Association of Canada, Special Paper 41: 127-136.

Weddle, T. K., 1992. Late Wisconsinan stratigraphy in the lower Sandy River valley, New Sharon, ME: Geological Society of America, Bulletin 104: 1350-1363.

Wilson, K.R. 2006. Ecogeomorphology of salt pools of the Webhannet estuary, Wells, Maine, USA. Masters thesis, University of Maine, Orono, ME. 98 pp.

Wood, M.E., Kelley, J.T. and Belknap, D.F., 1989. Patterns of Sediment Accumulation in the Tidal Marshes of Maine. Estuaries, 12(4): 237-246.

CHAPTER 15

Physical Influences on the Biota

MICHELE DIONNE

Water temperature, salinity, dissolved oxygen, water level, water velocity, ice and mineral substrate type are the primary abiotic factors that determine the living conditions for biological organisms in the Webhannet and Little River estuaries. These abiotic drivers are dynamic at several time scales: that of the tidal cycle, the diurnal cycle and the seasonal cycle. They are subject to even greater dynamics during episodic storm events. Through the National Estuarine Research Reserve System (NERRS) Systemwide Monitoring Program (SWMP), we can describe the abiotic conditions in the water column based on data from instruments stationed at inlet and head of tide, in both the Webhannet and Little River estuaries.

TEMPERATURE

Temperature is the dominant underlying regulator of biochemical reactions, and thus controls metabolic and growth rates, determines survival limits and even influences life history evolution of organisms (Clarke and Fraser 2004, Charnov and Gillooly 2004, Begon *et al.* 2006). Caffrey (2004) found that temperature was the most important environmental driver of whole system metabolism within estuaries of the NERRS. Using 2005 as an example, seasonal variation in water temperature for the Webhannet and Little River estuaries mirrors that of Gulf of Maine surface waters measured at the Gulf of Maine Ocean Observing System Western shelf monitoring station.[1] Peak temperatures occur from mid-July through August, although the Webhannet inlet tends to run about 5°C cooler than the Gulf. For the Webhannet, the head of tide site is warmer on average than the inlet (by 3.7°C, Table 15-1, Fig. 15-1), while the Little River is thermally similar at head tide and inlet. From mid-October through December this relationship reverses, with the head of tide sites becoming 1.5° to 3°C cooler than the inlet sites, for the Little River and Webhannet respectively. This is likely a function of the much shallower depths at the head of tide, and the distance from the thermal mass of the Gulf of Maine. The monitoring loggers are removed during the ice-up period from all but the Webhannet inlet site, hence data is lacking for the coldest months of each year.

On the temporal scale of the tides, inlet water temperature is clearly linked with the ebb and flood of Gulf of Maine water for both systems, with temperatures warming at low tide in June, and cooling at low tide in November

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[1] For a map of bouy locations and to view current data see http://www.gomoos.org. The three buoys referenced in this chapter are B0112 on the Western Maine Shelf (43°10’51” N, 70°25’40” W), A0117 at Massachusetts Bay (42°31’40”, 70°33’59” W, and C0212 at Casco Bay (43°34’10” N, Longitude: 70°03’18” W).

	All months [1]		July 15th - Aug 31st		Oct 15th - Dec 15th	
	mean	s.e.	mean	s.e.	mean	s.e.
Little River Inlet						
Temperature (°C)	6.476	0.053	19.461	0.049	6.77	0.06
Dissolved Oxygen (mg/L)	12.252	0.025	7.412	0.057	9.48	0.07
Salinity (ppt)	9.000	0.106	22.469	0.173	11.45	0.23
Webhannet Inlet						
Temperature (°C)	3.638	0.042	16.502	0.037	8.91	0.04
Dissolved Oxygen (mg/L)	7.775	0.033	3.730	0.099	4.39	0.05
Salinity (ppt)	31.118	0.013	30.751	0.006	31.14	0.02
Webhannet Head of Tide						
Temperature (°C)	6.028	0.058	20.220	0.037	5.69	0.06
Dissolved Oxygen (mg/L)	13.602	0.022	8.411	0.031	13.31	0.02
Salinity (ppt)	0.067	0.036	3.590	0.144	0.11	0.01
Little River Head of Tide						
Temperature (°C)	6.266	0.058	19.776	0.039	5.42	0.07
Dissolved Oxygen (mg/L)	12.916	0.028	7.883	0.010	13.24	0.03
Salinity (ppt)	0.000	0.000	0.080	0.001	0.00	0.00

[1] Webhannet Inlet is deployed all year; other stations deployed during ice-free months, typically March-December.

Table 15-1: Means and standard errors (s.e.) for the four water quality monitoring stations at Wells NERR.

(Figs. 15-2, 15-3). The temperature curve for the Little River is noticeably asymmetric. This pattern is caused by a natural sand delta forming a sill at the river's mouth. This sill extends the period of low tide until the incoming tide is high enough to spill over the sill and into the estuary. The period of flood tide is correspondingly shortened. At the head of tide, water levels and temperature show positive and inverse relationships (similar to those at the inlet sites), for June and November respectively, although water level curves (Figs. 15-2, 15-3) are quite different from those at the inlet, due to the distance from the tidal signal, and the influence of freshwater discharge from the watershed.

Violent waves crash into Laudhom Beach. Photo Michele Dionne.

Estuary temperature can also vary in response to episodic precipitation events, for example the precipitation event that occurred during October 7-11, 2005 (Fig. 15-4). Over the course of a 30-hour period of sustained rainfall with an hourly maximum of 100 mm, estuarine water temperature was depressed by 3°-4°C at all sites. Temperatures began to recover as the rains abated some 48 hours later.

DISSOLVED OXYGEN

Dissolved oxygen (DO) is required for metabolic respiration of all animals (i.e.,members of the Kingdom Animalia) found in the Reserve's estuaries and marshes. The Reserve's primary producers, on the other hand, not only use oxygen in respiration (with the exception of some photosynthetic microbes), but also generate oxygen as a byproduct of photosynthesis (during periods of sufficient photosynthetically active radiation, PAR). This leads to a characteristic daily variation in DO, with highest values at peak radiation and lowest values at the end of the dark period—the end of the respiration-only portion of the daily cycle. From a statewide survey targeting minimum DO values in 30 coastal waterbodies, the systems with the lowest minimum DO values were located primarily in marsh-dominated estuaries along Maine's southwest shore, and included the Reserve's two estuaries (Kelly

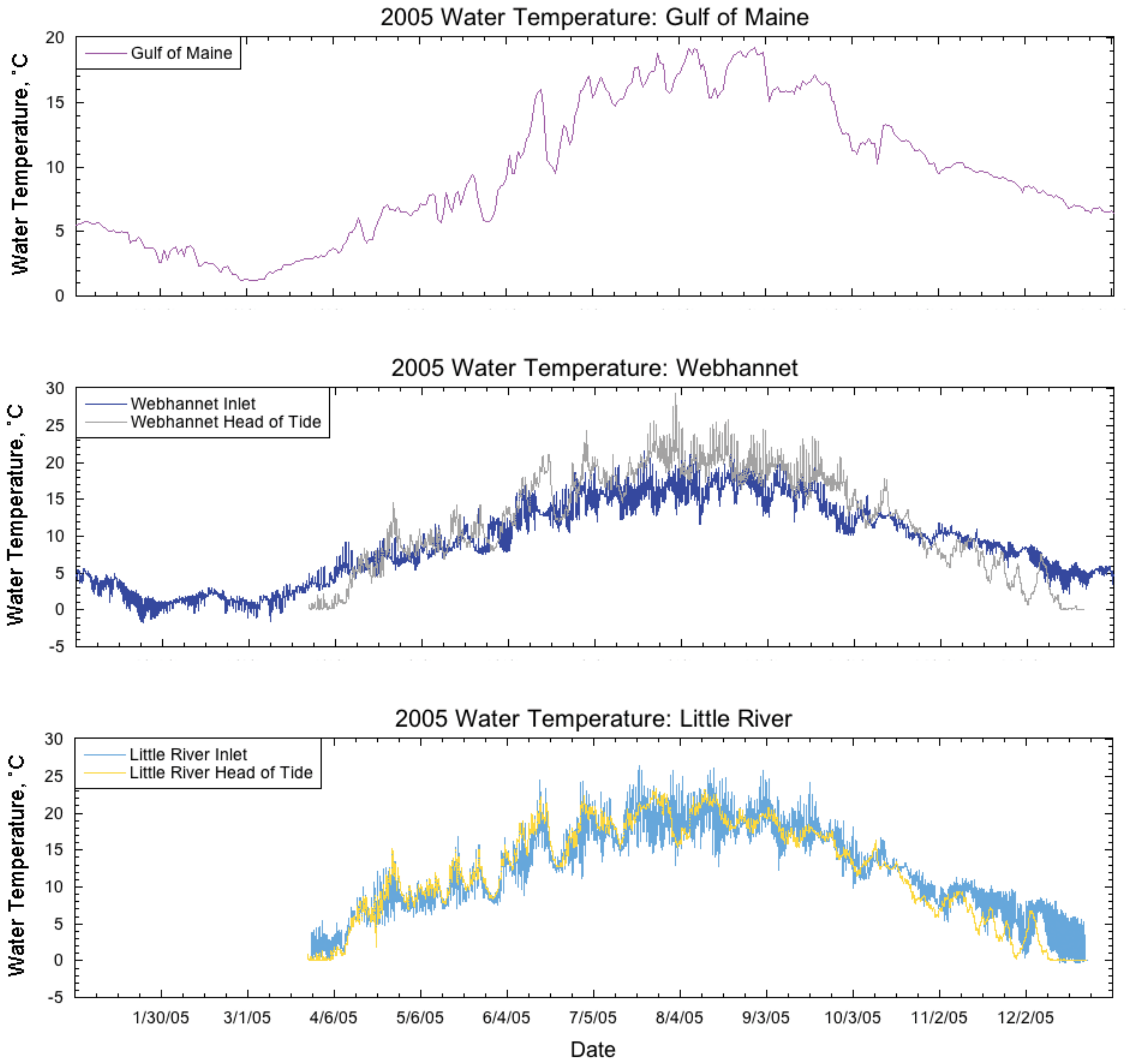
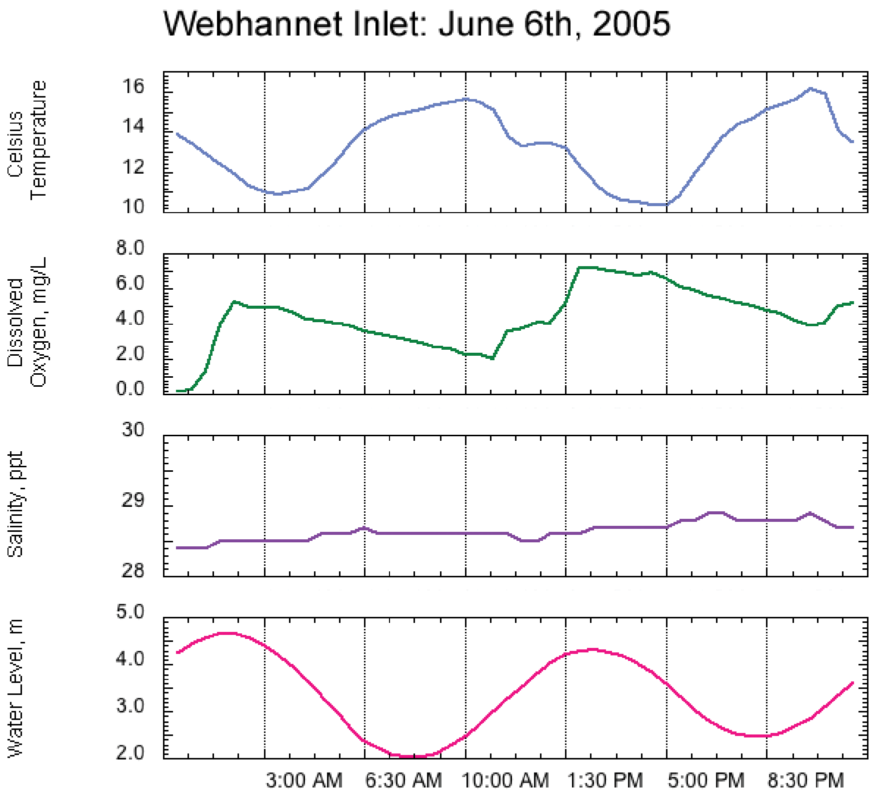


Figure 15-1: 2005 water temperature data for the Gulf of Maine Western Shelf, the Webhannet River and the Little River. Data gaps in the two lower graphs show times when loggers were removed due to ice or extreme cold. Figure Hannah Wilhelm

1996, 1997). Even so, the mean of the lowest 5% of DO values collected did not descend below 5 mg L^{-1}, the point at which some estuarine organisms would begin to experience respiratory stress (USEPA 2000a,b).

It is likely that the low DO in these systems is explained, at least in part, by the highly organic substrates that characterize salt marsh systems. An analysis of estuarine net ecosystem metabolism (NEM) for the NERRS system (Caffrey 2004) determined that sample sites in proximity to organic substrates (e.g. salt marsh creeks) were likely to be strongly heterotrophic, when consumption of organic matter (and dissolved oxygen) exceeds production. In the Webhannet River, mean annual NEM at the head of tide SWMP station was -3.6 g O_2 m^{-2} day^{-1}, while the inlet site was autotrophic, with mean annual NEM of 0.9 g O_2 m^{-2} day^{-1}, despite regular low DO values at low tide. This site was one of three autotrophic sites of the 42 SWMP stations included in the study, representing 20 NERRS across all biogeographic provinces. The close



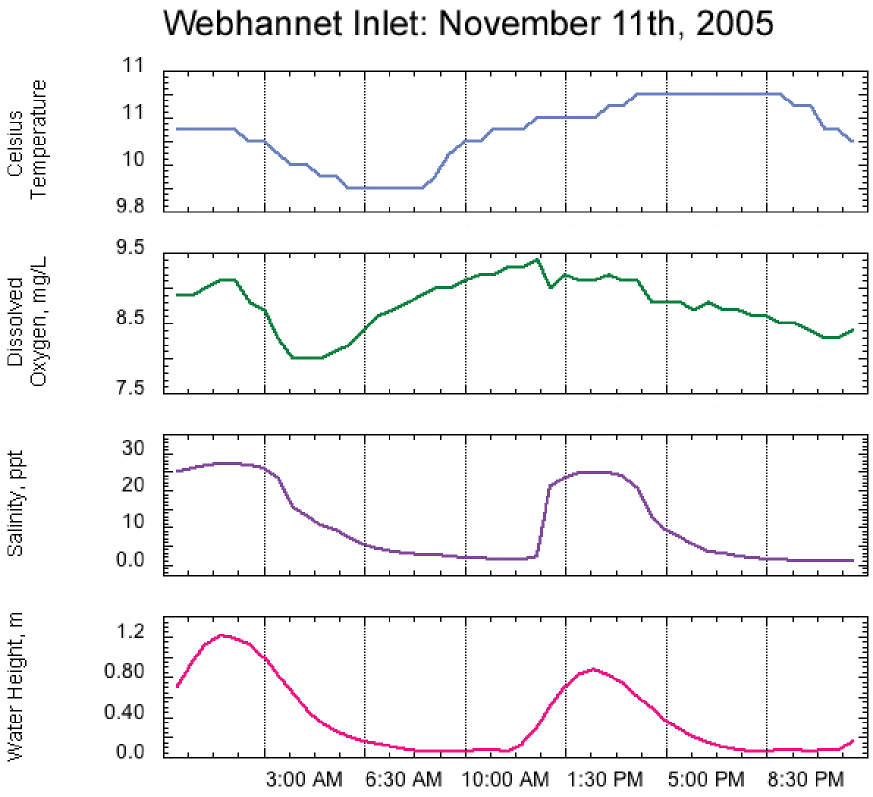
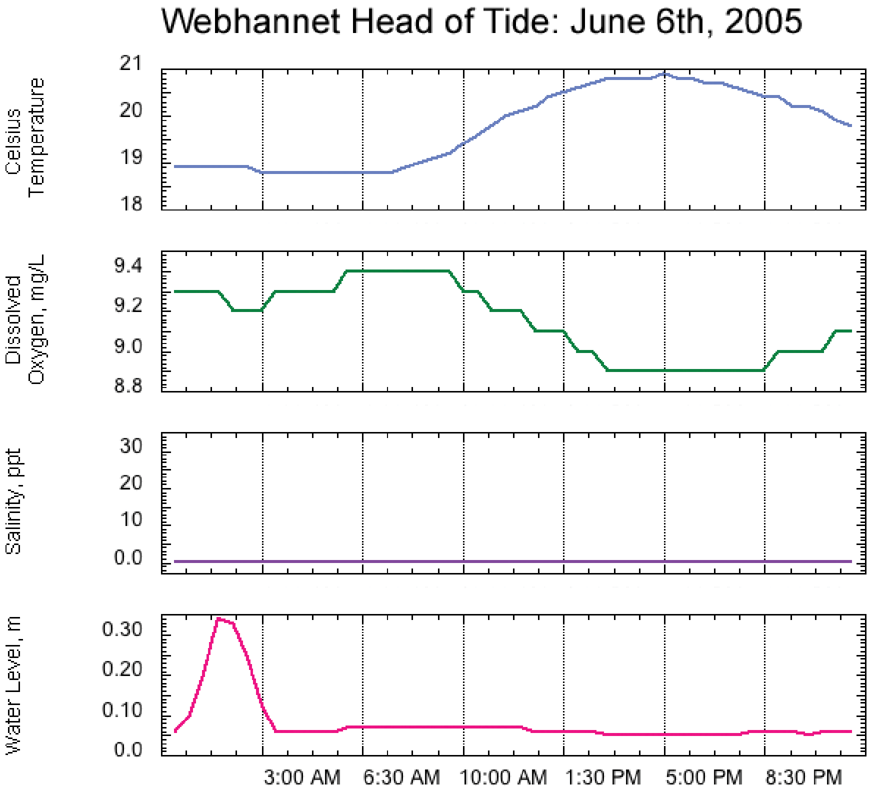
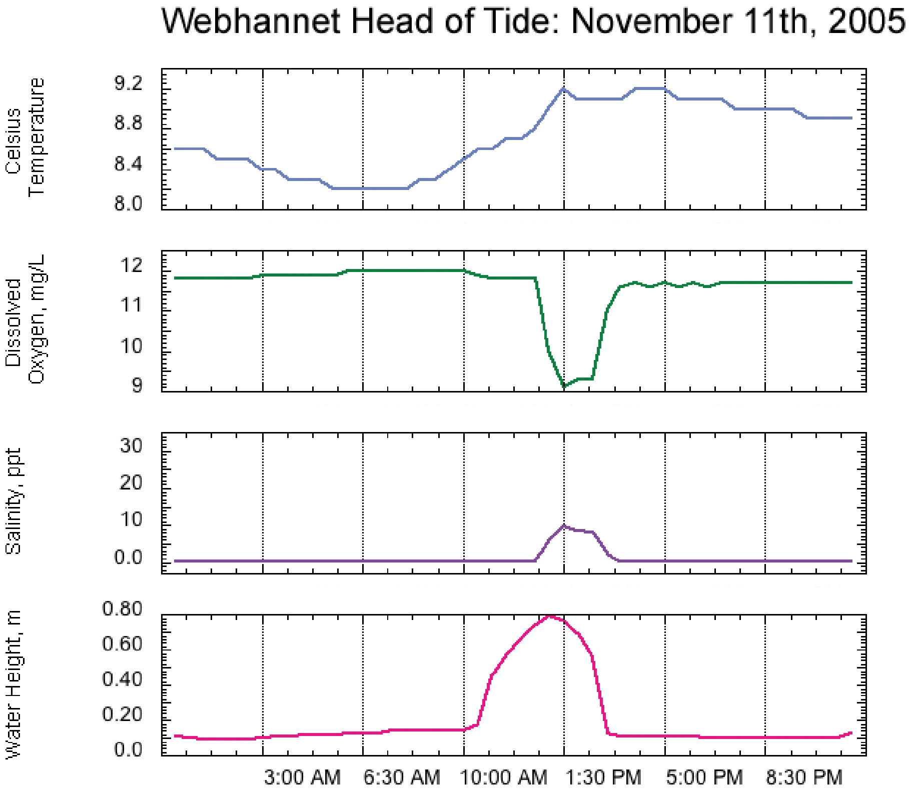


Figure 15-2: Water quality parameters for Webhannet River on two typical dates in 2005. Note differences in vertical scale. Figure Hannah Wilhelm.


Webhannet Head of Tide: June 6th, 2005
Celsius Temperature
21
20
19
18
Dissolved Oxygen, mg/L
9.4
9.2
9.0
8.8
Salinity, ppt
30
20
10
0.0
Water Level, m
0.30
0.20
0.10
0.0
3:00 AM
6:30 AM
10:00 AM
1:30 PM
5:00 PM
8:30 PM


Webhannet Head of Tide: November 11th, 2005
Celsius Temperature
9.2
8.8
8.4
8.0
Dissolved Oxygen, mg/L
12
11
10
9
Salinity, ppt
30
20
10
0.0
Water Height, m
0.80
0.60
0.40
0.20
0.0
3:00 AM
6:30 AM
10:00 AM
1:30 PM
5:00 PM
8:30 PM

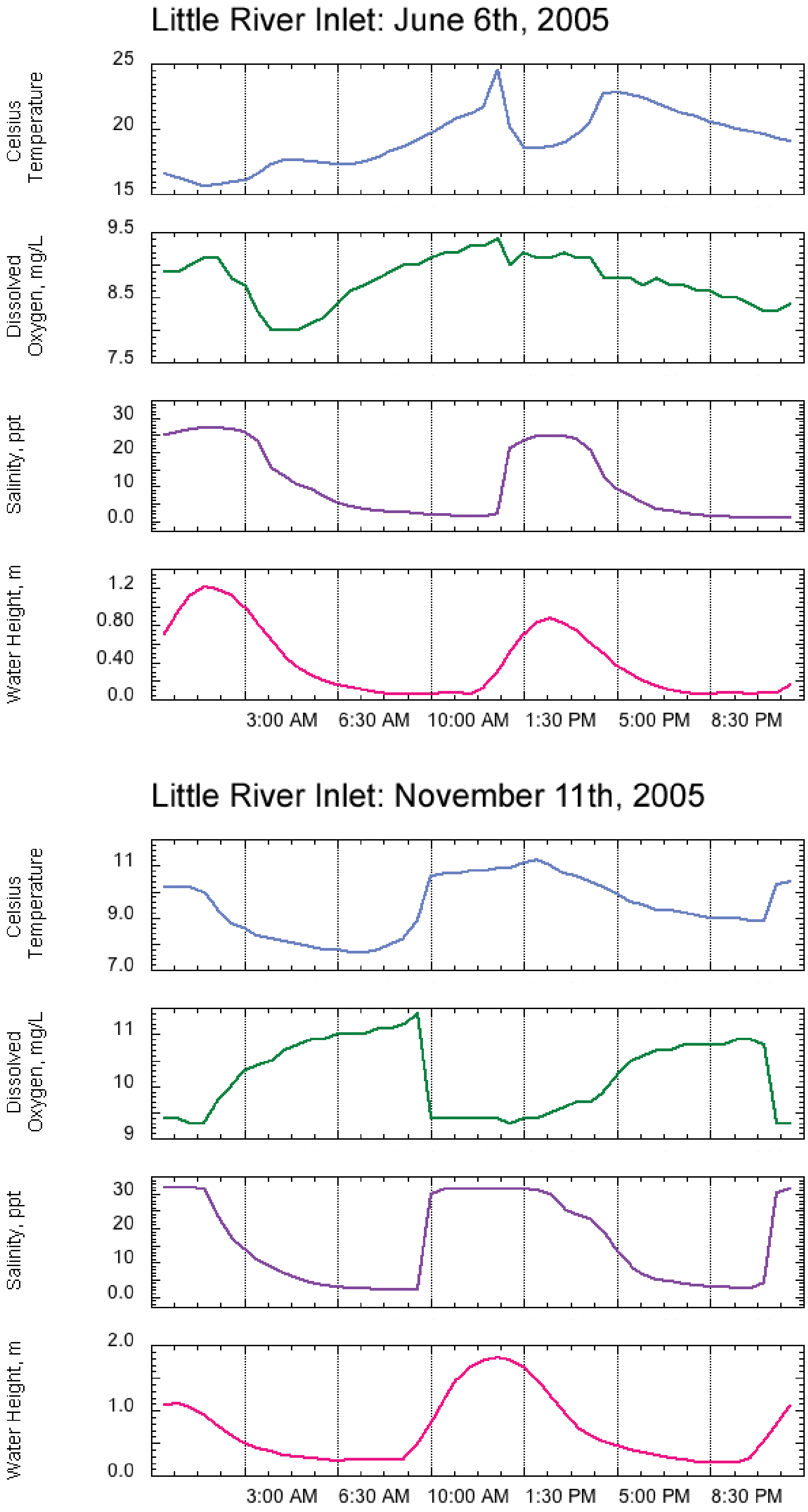
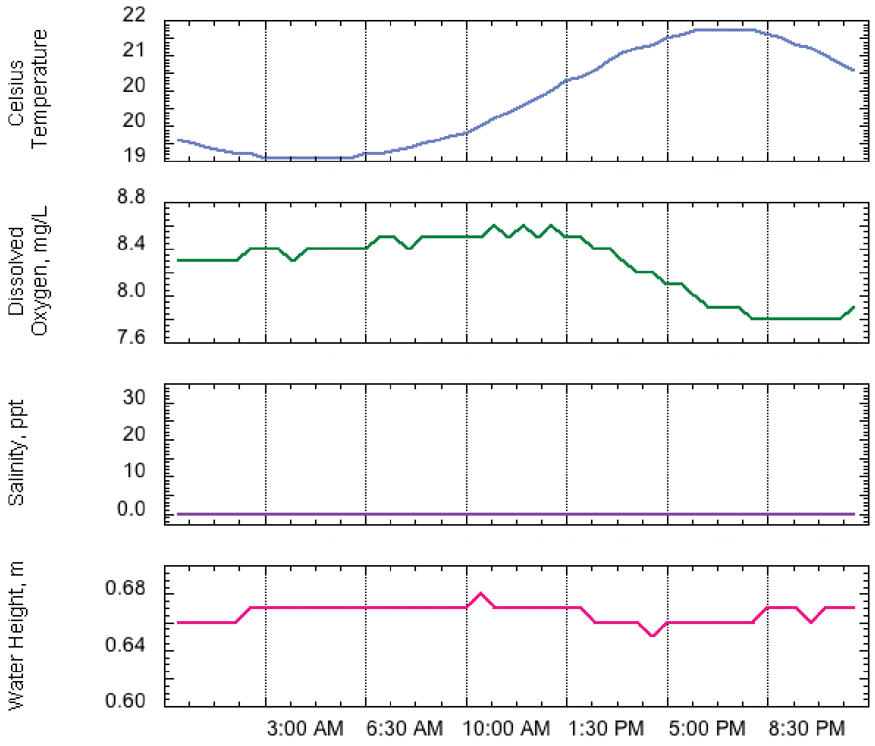
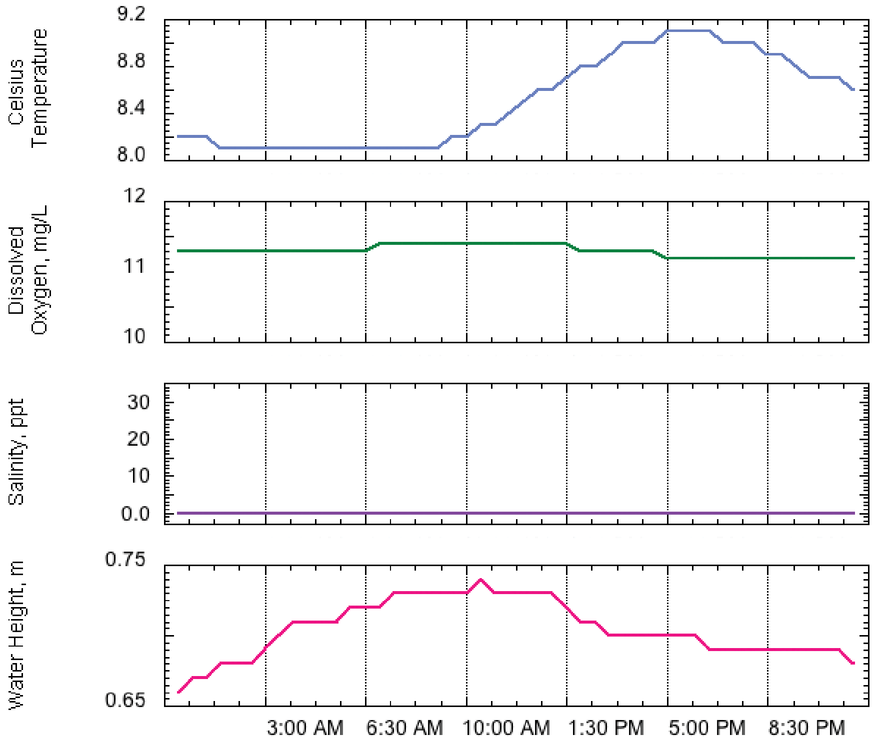


Figure 15-3: Water quality parameters for Little River on two typical dates in 2005. Note differences in vertical scale. Figure Hannah Wilhelm.



Little River Head of Tide: June 6th, 2005



Little River Head of Tide: November 11th, 2005

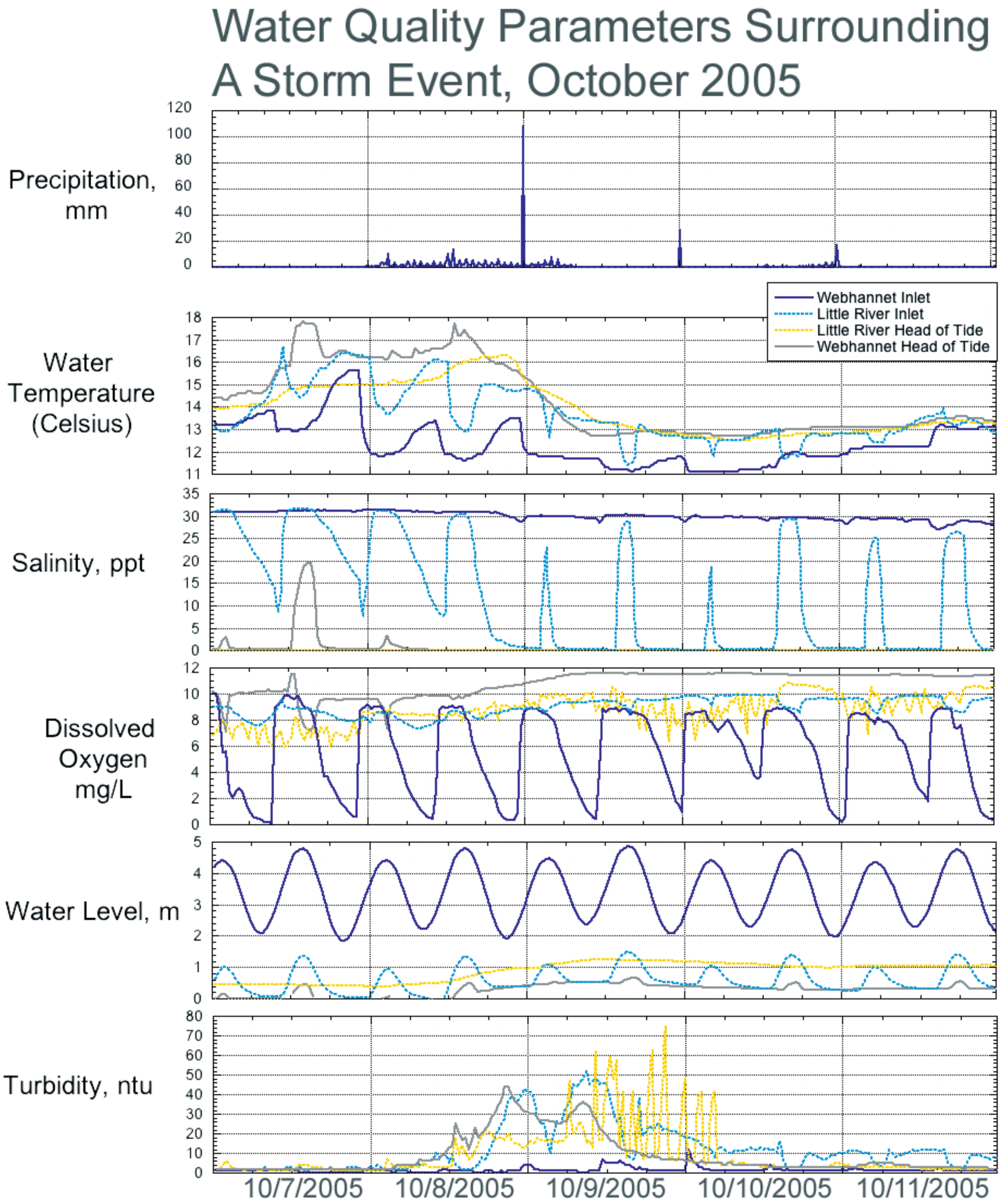


Figure 15-4: Water quality parameters and precipitation for October 7th – 11th 2005. Note the heavy rainfall near midnight on the 8th. Figure Hannah Wilhelm.

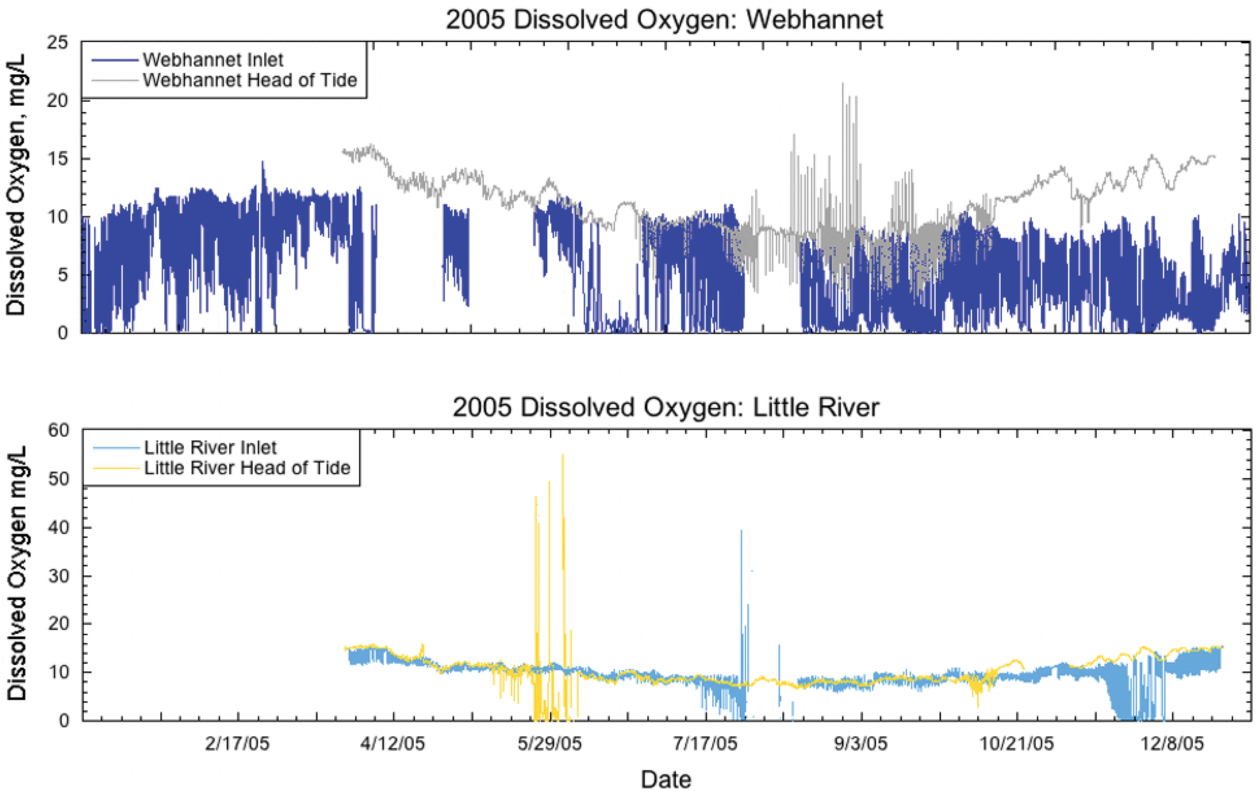


Figure 15-5: Dissolved Oxygen data for 2005 for the Webhannet River and Little River. Figure Hannah Wilhelm.

proximity of the Webhannet inlet site to the open waters of the Gulf of Maine, renowned for its high productivity, may well explain this result.

Using 2005 as an example, seasonal variation in dissolved oxygen at high tide shows a gradual decline from peak values during the winter months, when water temperature is lowest, corresponding to highest oxygen solubility (Fig. 15-5). DO declines from a typical high of ≈ 12 mg L^{-1} in February and March to a typical low of ≈ 8 mg L^{-1} in October and the first half of November. From mid-November through December, high tide DO is frequently surprisingly low (≈ 5 mg L^{-1}). There is an episode of uncharacteristically low DO in mid-June as well. On the low tide, DO drops to very low values (≈ 2 mg L^{-1}) more frequently from June through early January

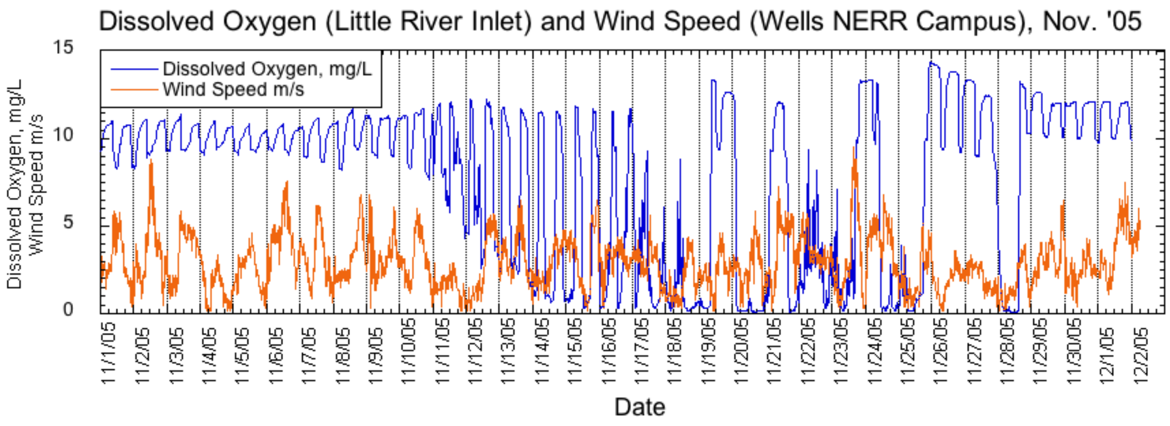


Figure 15-6: Wind speed and dissolved oxygen for November 2005 in the Little River inlet. Figure Hannah Wilhelm.

(see discussion regarding low tide low DO below). The annual mean DO for the Webhannet inlet station is consequently ≈ 4.5 mg L^{-1} lower than for the Little River (Table 15-1). There is also a substantial increase of nearly 6 mg L^{-1} from inlet to head tide in the Webhannet.

In the Little River inlet, DO shows a different pattern, with highest values in spring and fall (≈ 14 mg L^{-1}), dipping to lower values from mid-July through September (≈ 8 mg L^{-1}). This pattern is the inverse of Little River inlet water temperature, and thus appears to be driven by oxygen solubility, save for two episodes of much lower DO in late July and late November. One plausible explanation is that a large amount of drift algae was driven into the Little River by winter storm conditions, as happens frequently. This organic matter would begin to decay through bacterial respiration, driving down dissolved oxygen levels, especially at low tide. An inspection of wind speed data from the Reserve's weather station (about 0.5 km distant) does not reveal a precipitating wind event (Fig. 15-6), although a storm surge propagated offshore might be responsible for the deposition of drift algae in the Little River. The low DO in late July may also be driven by water column stratification, when water of different densities form layers or strata, preventing atmospheric oxygen from mixing with the lower stratum. In a prior survey of dissolved oxygen conditions in the Little River (Kelly 1996), we observed salinity stratification in the Little River associated with low dissolved oxygen at low tide (Fig. 15-7), when benthic respiration could drive down dissolved oxygen in the relatively small water volume.

The head of tide stations in both estuaries show a common warm-weather DO depression, from ≈ 16 down to ≈ 8 mg L^{-1} in both the Webhannet and Little River (Fig. 15-5). Both systems also show episodes of great variation, especially in the upward direction, with supersaturation exceeding 20 mg L^{-1} in the Webhannet and 50 mg L^{-1} in the Little River. Supersaturation could be the result of atmospheric mixing during periods of high water discharge, or photosynthesis, especially during periods of low flow when water volumes are minimal at these sites. The pattern of alternating supersaturation and below average DO values observed here may be explained by day time photosynthesis and night time respiration of benthic microalgae. During the fall (15 October – 15 December) both systems have similar high DO at head tide (≈ 13 mg L^{-1}), while the two inlets show a substantial difference, ≈ 9.5 mg L^{-1} at the Little River, and ≈ 4.5 mg L^{-1} for the Webhannet (Table 15-1).

On the temporal scale of the tides, inlet dissolved oxygen variation is a function of estuarine processes, rather than conditions in the Gulf of Maine (Figs. 15-2, 15-3). DO in the Webhannet inlet shows a regular and drastic depression at low tide (both in June and November), possibly linked to the accumulation of organic matter around the harbor docks from lobster bait effluent discarded by visiting bait dealers (Fig. 15-2). This phenomenon appears to be local, since the DO surveys conducted in 1995 and 1996, and the benthic habitat mapping in 2001 (Diaz et al. 2005), in the open waters of the harbor, not far from the docks, did not reveal DO minima below 5 mg L^{-1}. A spatial survey of surface waters in the Webhannet River in 2004 (Fig. 15-8) revealed normal DO levels at both

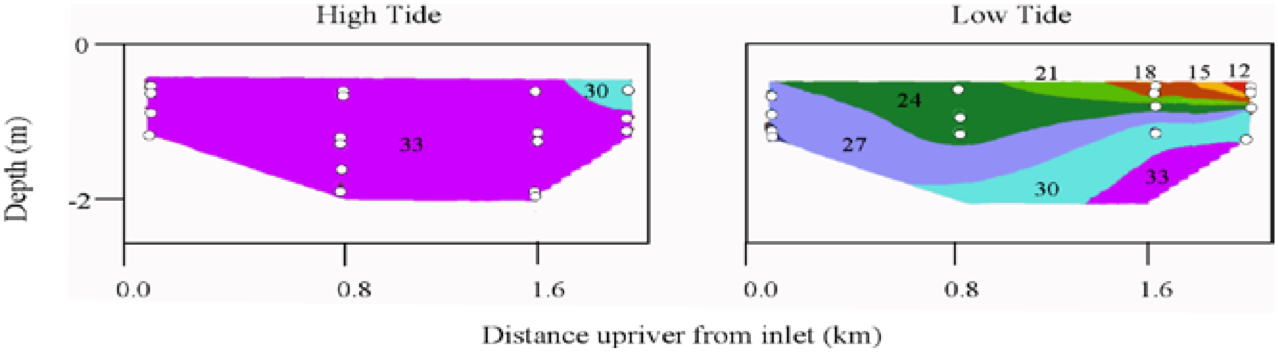


Figure 15-7: Vertical and horizontal salinity gradients in the Little River Estuary, Wells and Kennebunk, Maine (September 1995). Freshwater draining from the watershed flows over Gulf of Maine nearshore water during the ebb portion of the tidal cycle. Contours based on data collected at indicated points. Dissolved oxygen at low tide ranged from 5.5 to 6.0 mg L^{-1} in the lower strata (adapted from Kelly 1996).

high and low tide. DO at the Little River inlet in June shows a pattern that is likely driven by water column primary production, with a predawn minimum increasing till midday, in spite of rising water temperature, which reduces oxygen solubility. DO gradually declines with the angle of the sun from midday to sundown. In November, DO is driven by tidal variation in water temperature, providing a mirror image to tidal fluctuations in temperature and water level. Respiration and photosynthesis do not play an obvious role when water temperatures are lower, and days are shorter. At the head of tide (HT) in the Webhannet, dissolved oxygen is much higher in June than at the inlet (IN), resulting from the turbulence created by the Webhannet Falls just upstream. In November, DO is constant and again, substantially higher than at the inlet, except for the brief period (3 hrs) when tidewater reaches the station. During tidal inundation, DO values decline to levels similar to those at the inlet during high tide (9 vs. 8 mg L^{-1} for HT and IN respectively).

SALINITY

Both estuaries are tidally dominated systems, with salinities at the inlet similar to those of the coastal Gulf of Maine (28-32 PSU, practical salinity units), with lower salinities occurring during the spring freshet and episodes of high precipitation (Bigelow 1927). Ocean salinities worldwide range from 33-37 PSU (mean is 35 PSU). Biological communities within the estuary are structured by salinity at several thresholds (as shown for 316 animal species in Mid-Atlantic estuaries): 0-4 PSU, 2-14 PSU, 11-18 PSU, 16-27 PSU and > 24 PSU (Bulger *et al*. 1993). Salinity is the dominant factor driving estuarine fish distribution (Monaco *et al*. 1998). Plant distributions respond to salinity (Rand 2000, Bertness and Ewanchuk 2002, Ewanchuk and Bertness 2004a, Crain *et al*. 2004) and tidal inundation and drainage (Hacker and Bertness 1999, Ewanchuk and Bertness 2004b). These two drivers are closely linked in New England salt marsh ecosystems.

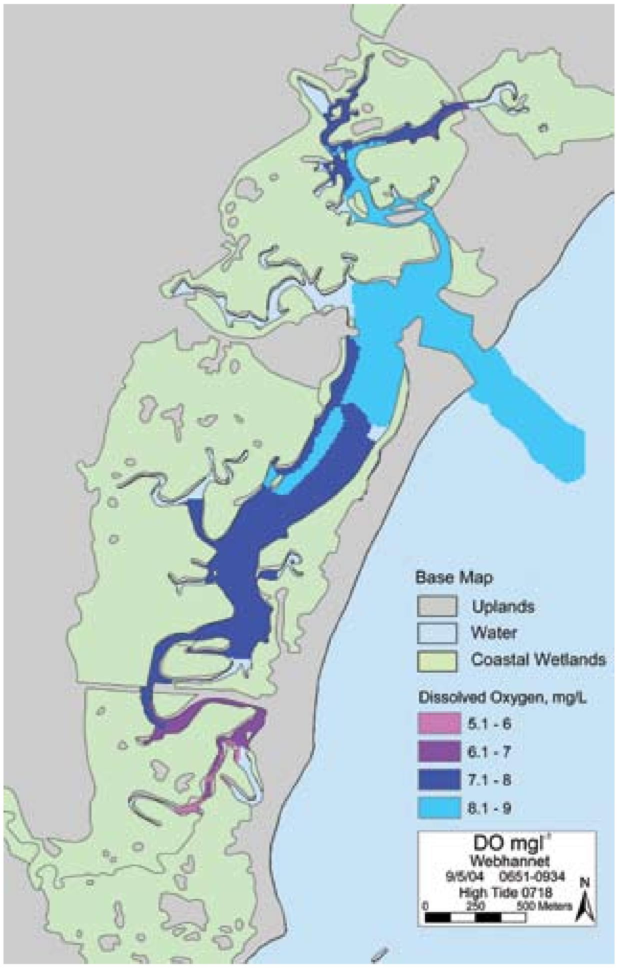


Figure 15-8: Dissolved Oxygen zones of the Webhannet estuay at high tide. Map Wells NERR.

Using 2005 as an example, seasonal variation in salinity for the Webhannet River inlet mirrors that of Gulf of Maine surface waters (measured at the Gulf of Maine Ocean Observing Casco Bay Buoy location 1) (Fig. 15-9). Salinity varies from 28-32 PSU on a fine temporal scale throughout the year, punctuated by several lower salinity episodes in March (≈ 22 PSU), May (≈ 22 PSU) and October (≈ 20 PSU), associated with precipitation events. At the Little River inlet, during high tide, salinity shows a somewhat larger fine scale variation, from 22-32 PSU. At low tide salinities drop below 2 PSU during much of the year, consequently the annual mean salinity for the Little River inlet is 22 PSU, lower than for the Webhannet (Table 15-1). Salinity increases from 5 up to 25 PSU from June through early October, again punctuated by a number of low salinity episodes. The monitoring loggers are removed during the ice-up period from all but the Webhannet inlet site, hence data is lacking for the colder months of each year. The head of tide salinity regime on the Webhannet River hovers around 0 during spring and early summer, and again in the fall, but during the summer, when freshwater discharge from the watershed is reduced, salinities increase greatly at high tide, typically within the range of 8 to 28 PSU, with a mean of 3.6

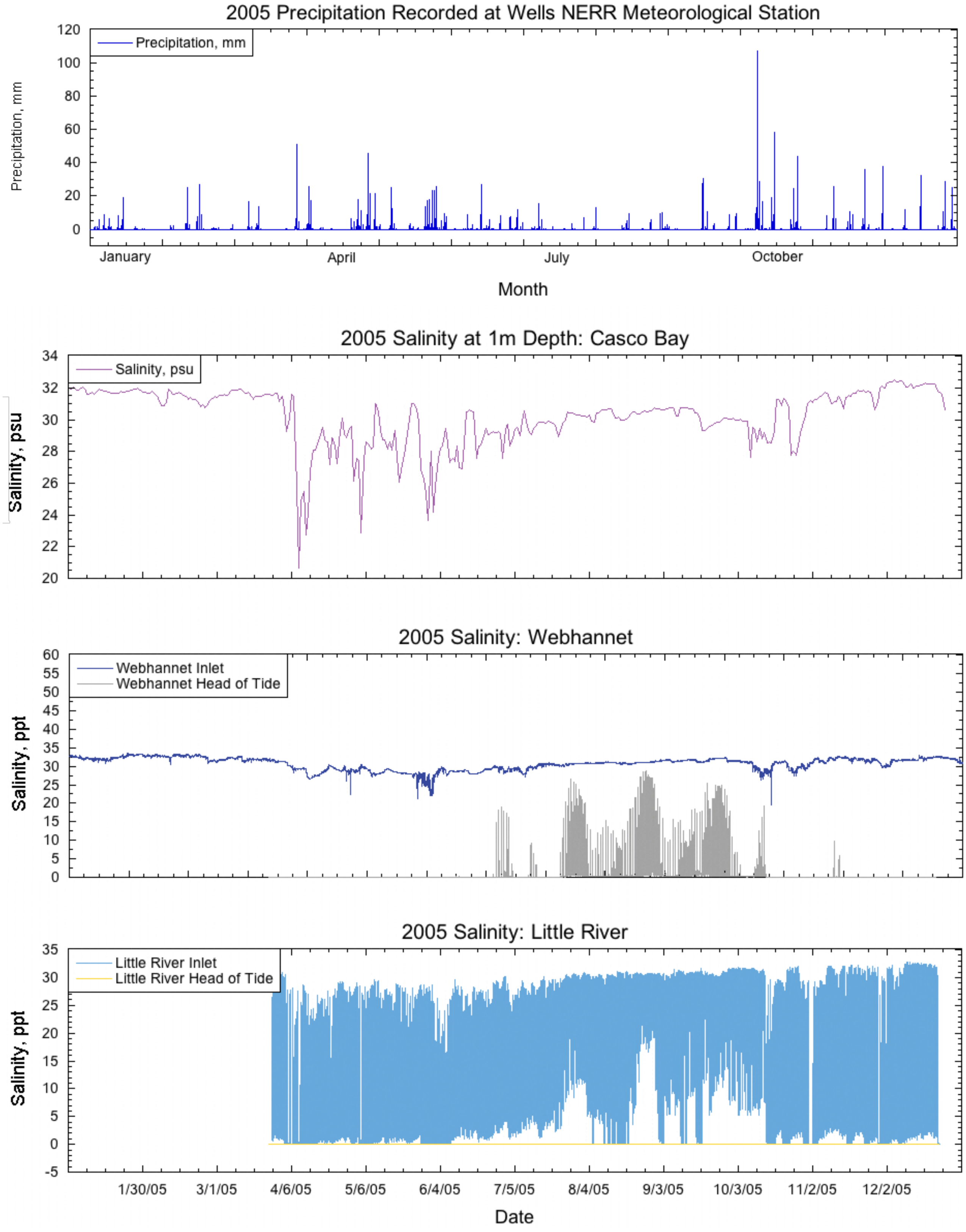


Figure 15-9: Salinity in Casco Bay, the Webhannet River and the Little River for 2005, along with precipitation measured at the Wells NERR SWMP meteorological station. Figure Hannah Wilhelm.

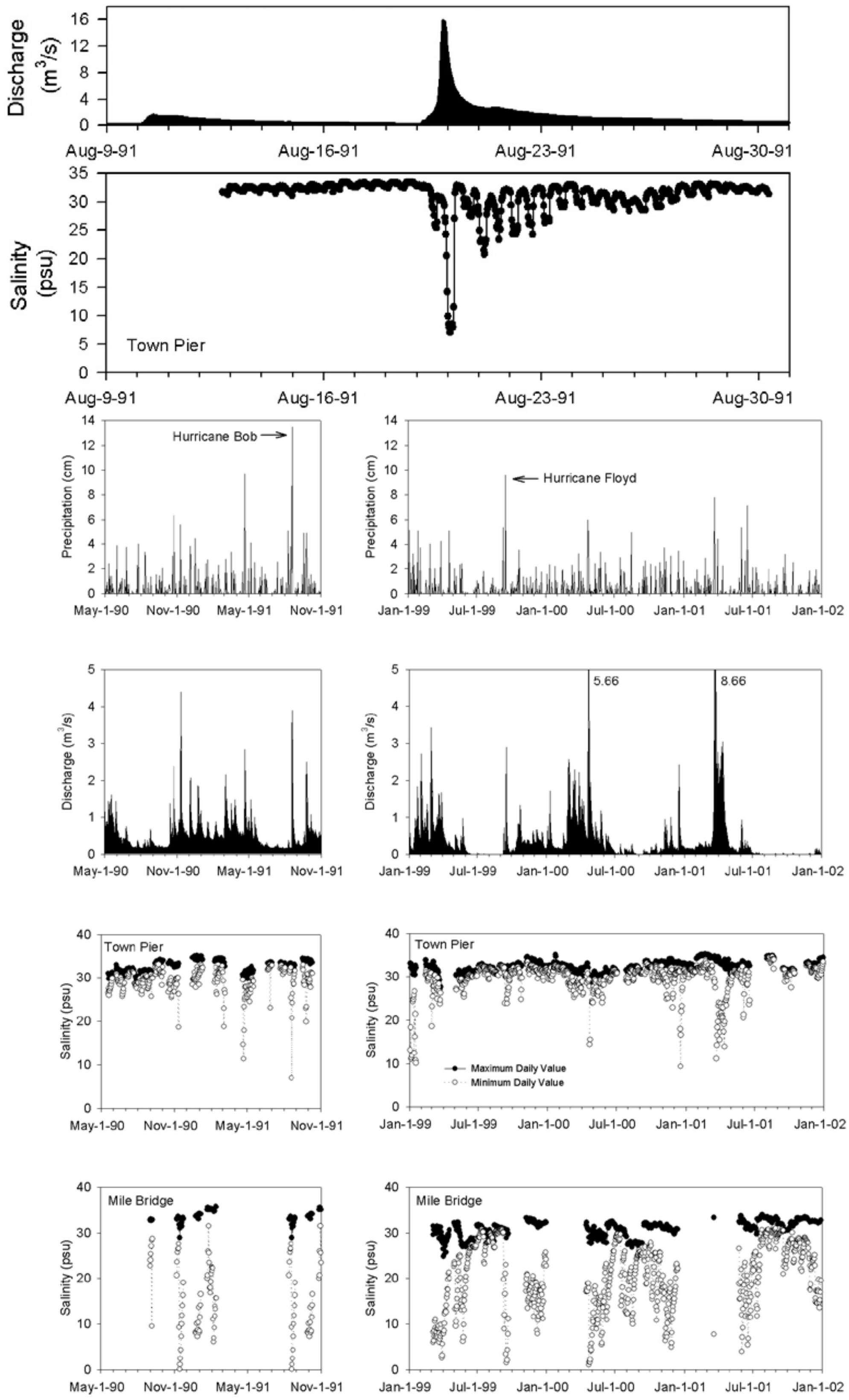


Figure 15-10: Stream discharge, precipitation and salinity surrounding Hurricane Bob in 1991. Copyright © 2004 Coastal Education and Research Foundation. From Journal of Coastal Research by L.G. Ward. Reprinted by permission of Alliance Communications Group, a division of Allen Press, Inc.

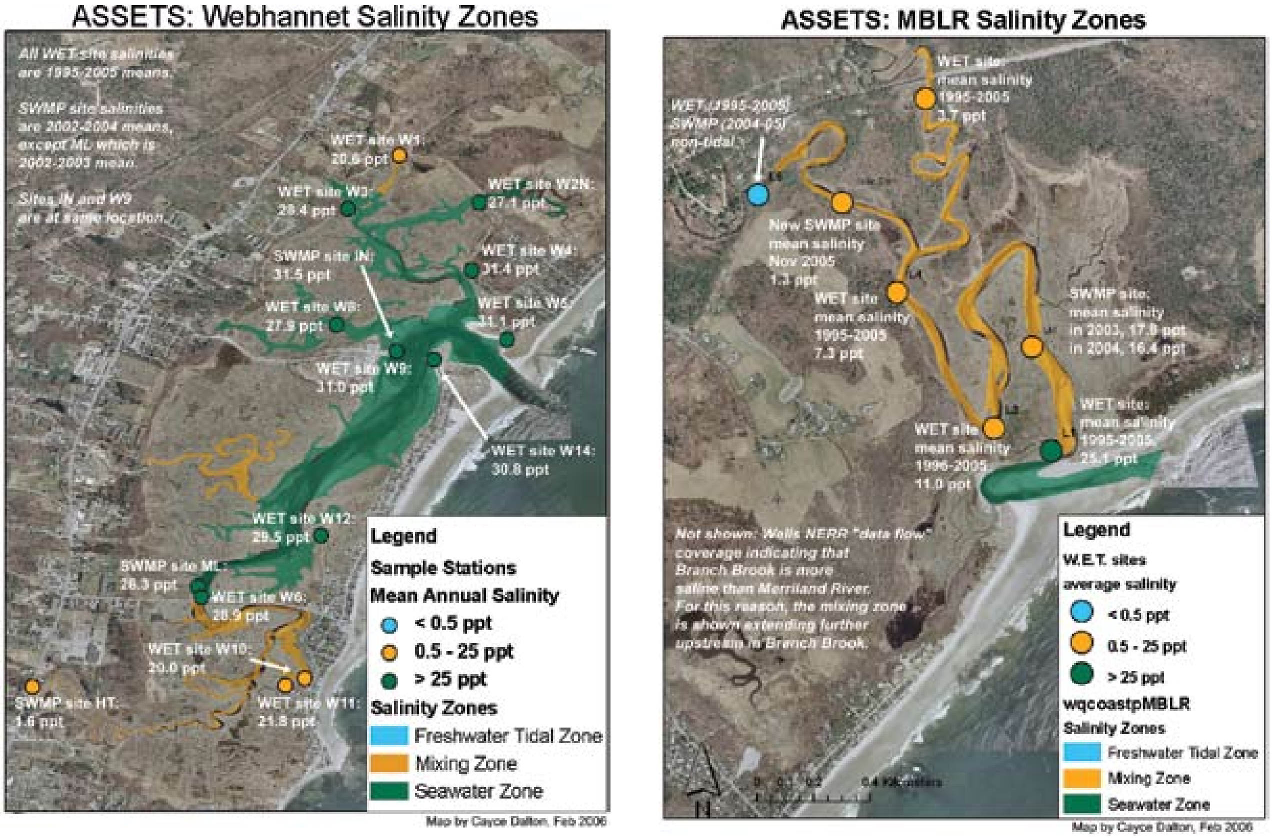


Figure 15-11: Salinity zones of the Webhannet River and the Little River.

PSU from 15 July through 31 August (Table 15-1). By contrast, the head tide station on the Little River appears to be above the reach of salt water influence, remaining at 0 PSU throughout the year, and with a mean of 0.08 PSU during the period of reduced freshwater discharge. In the fall (15 October to 15 December), average head tide salinity in the Webhannet is reduced to 0.11 PSU, while the Little River head of tide remains at 0.0 PSU. In 2006, the Little River head of tide station was moved somewhat downstream in order to capture the interaction between freshwater discharge and tidal salt water.

On the temporal scale of the tides, there is little variation in salinity through the tidal cycle at the Webhannet inlet, although there is a small seasonal variation associated with periods of snow melt and precipitation (June vs. November, Fig. 15-8). For the Little River inlet, there is a dramatic change in salinity from high to low tide (Fig. 15-3). The sill at the river's mouth retains water in the estuary at low tide, which becomes progressively fresher as freshwater discharges into the estuary's main channel. This trend is abruptly reversed when the flood tide begins to spill over the sill and into the estuary. At the head of tide, salinities often drop to the freshwater range at low tide (< 0.5 ppt), and during major precipitation events, even the Webhannet inlet can become brackish for a period of time (Ward 2004).

The National Oceanic and Atmospheric Administration (NOAA) has developed criteria for estuarine salinity zones, to broadly categorize the interaction between estuarine physical and biological processes. The freshwater tidal zone includes waters that are typically < 5 PSU, the mixing zone includes waters from 5 to 25 PSU, and the seawater zone includes waters > 25 PSU. When this zonation scheme is applied to the Reserve's estuaries, the great majority of the estuarine surface area falls within the mixing zone for the Little River, and within the seawater zone for the Webhannet River (Dalton *et al.* 2006, Fig. 15-11). These contrasting conditions in two adjacent estuaries reflect the large differences in watershed size and freshwater discharge, relative to tidal prism (Kelly 1996, 1997). Another interesting difference in the salinity regimes of these systems is the result of tidal inlet geomorphology. The Webhannet system has a deep, dredged inlet that leads to near complete drainage of the estuary at low tide, while the Little River has a naturally maintained inlet, with a sand bar that acts as a sill to retain water within the estuary at low tide, and to lengthen the duration of low tide. Given that the estuary has a large watershed relative to its tidal prism, freshwater accumulates in the estuary at low tide, until the incoming tide begins to spill over the sill. The estuary can become progressively fresher at low tide during periods of high freshwater discharge. Both systems achieve freshwater tidal conditions at the head of tide. In the Webhannet, this zone is truncated by a natural fall line, the Webhannet Falls (see photo), which demarcates the farthest extent of tidal influence, creating a very short freshwater tidal zone. In the Little River, the farthest extent of tidal influence is demarcated by an historic dam foundation on the Merriland River tributary, restricting the freshwater tidal zone artificially. On the Branch Brook tributary, there appears to be an extensive freshwater tidal zone upstream of the Reserve's boundaries that should be mapped and described.

In the vertical dimension, the Webhannet estuary is shallow and well mixed by strong flooding tides through the dredged inlet, hence not prone to stratification, a result of its large tidal prism relative to freshwater inflow. The Little River can stratify at low tide, when the volume of freshwater is large relative to the volume of seawater. Under these conditions, dissolved oxygen below the chemocline can become depleted (Fig. 15-7).

Webhannet Falls. Photo Sue Bickford.

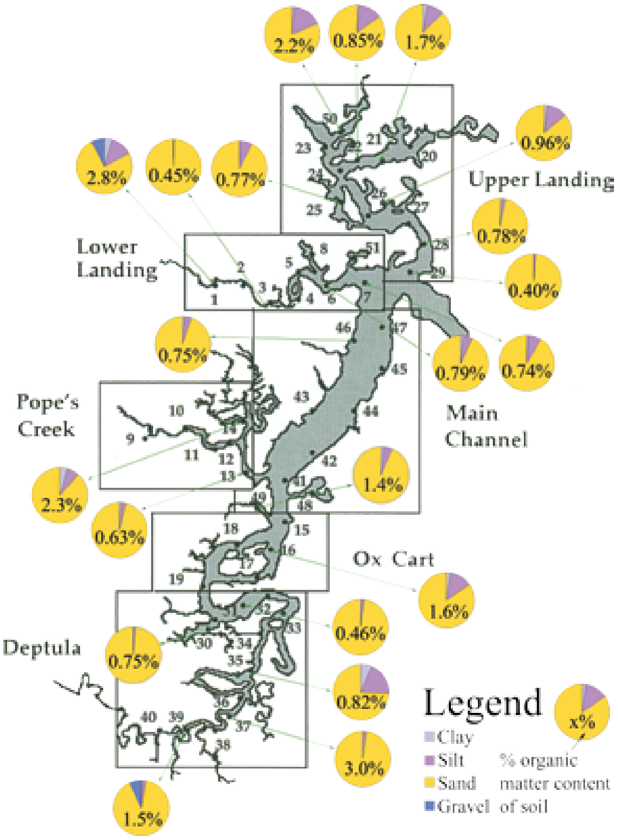


Figure 15-12: Grain size and percent organic matter content of representative soil core samples collected on the Webhannet marsh (Milbury 1997). Figure Hannah Wilhelm
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BENTHIC SUBSTRATES

The Webhannet River estuary contains a working harbor maintained by the Army Corps of Engineers, and also supports a recreational softshell clam and baitworm fishery. Consequently, the substrate and benthic invertebrate fauna of this system have been surveyed to inform manageme these coastal assets.

Beginning in 1996, Wells NERR has assessed the softshell clam population of the Webhannet estuary periodically, to inform resource management by the municipality and the state. As an extension of this work, Milbury (1997) investigated the relationship between newly settled, or

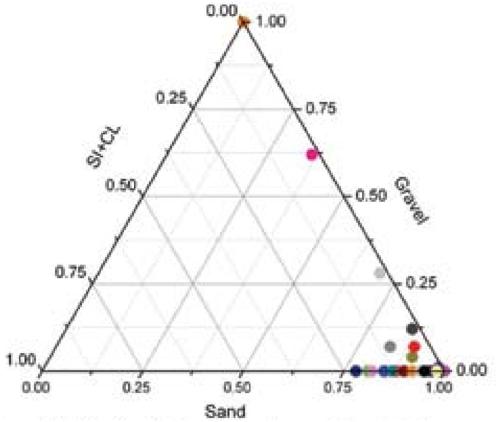


Figure 15-13: Percent silt (SL) and clay (CL), sand, and gravel for all stations surveyed on the Webhannet river system for Wells NERR Benthic Habitat Mapping Project (Diaz *et al.* 2005). Colors are used to distinguish individual samples.

'seed' clam and substrate composition, among other variables. She found a significant, positive, nonlinear effect of % total organic content (TOC) on juvenile clam density, with high explanatory value ($R^2 = 0.99$). As for grain size, only gravel had a significant (negative) influence on clam density, in a multiple regression model ($R^2 = 0.20$). When organic content was included in the model, the variation in clam denstiy explained by the model increased to $R^2 = 0.29$. Although the strength of the associations between clam density, organic content, and grain size would appear modest, it is remarkable considering the greatly restricted scope of grain size variation in the Webhannet system, being sand-dominated with very low organic content (Fig. 15-12).

In 2001, NOAA's Coastal Services Center collaborated with the Reserve to survey the Webhannet estuary to establish a post-dredge baseline of benthic habitats and infaunal communities (Diaz *et al.* 2005). A combination of grab samples (n=47) and sediment profile imaging (n=190) was used to characterize sediment texture, sediment surface and subsurface features, infaunal communities, and benthic habitat quality. Here we will highlight findings regarding substrate and benthic infauna. Consistent with Milbury's work, the system is sand dominated, with 31 of 47 stations classified as fine sand in the Wentworth classification, and only 3 stations as coarse or coarser than gravel (Table 15-2). Total organic carbon was < 1% at most stations. ($\bar{x} = 0.46\%$ ±0.09 SE). The 6 stations that had >1% TOC also had more than twice the mean proportion of silt+clay ($\bar{x} = 11.2$ ±3.12 SE vs. $\bar{x} = 4.9$ ±0.76 SE).

A total of 40,642 individuals representing 78 taxa were collected from the Young grabs (0.044 m^2 surface area). Cluster analysis revealed four dissimilar station groups and five distinct species groups that formed primarily around differences in sediment preference and abundance (Table 15-3). Group I stations had the highest TOC, and high abundances of species preferring mud substrates (e.g. *Streblospio benedictii*, *Capitella capitata*, and oligochaetes. Group II stations had similar taxa but lower abundances of numerical dominants than Group I, and included high abundances of *Corophium volutator*. Group III was characterized by high abundance of *Pygospio elegans*. Mud-dominant species were poorly represented in Group IV, which was dominated by sandy substrate, high salinity species (e.g. *Paraonis fulgens* and *Aricidea caterinae* with high densities of *Mytilus edulis*), and spatially clustered in the Harbor/Inlet portion of the estuary. Species Group A contained muddy substrate species, Group B was composed of species associated with hard substrate, Group C included species preferring mixed sediments, while Groups D and E were characterized by sandy substrate species. Species Group A showed high

Wentworth Descriptor		Stations	Median Grain Size (Φ)		Percent Silt+Clay	
Abbreviation			Min	Max	Min	Max
CB	Cobble	1	.	.	0	0
CSGR	Coarse-sand-gravel	1	0.95	0.95	2	2
MS	Medium-sand	6	1.54	2.00	0	8
FSGR	Fine-sand-gravel	1	2.17	2.17	2	2
FS	Fine-sand	31	2.04	2.89	0	13
FSSI	Fine-sand-silt	3	2.74	2.96	15	22
VFS	Very-fine-sand	3	3.03	3.06	4	13
VFSSI	Very-fine-sand-silt	1	3.15	3.15	18	18

Table 15-2: Summary of sediment grain size from grab samples taken from the Webhannet. Sediment is classified using the Wentworth system with minimum and maximum values provided for median grain size and percent of silt + clay for each grain-size value (Diaz *et al.* 2002). Note: Φ is the $-\log_2 d$, where d is the diameter of the sediment particle in mm.

constancy (> 0.7, Fager 1963) within Station Groups I and II (e.g. was well distributed among stations within each group), while Species Group E showed strong fidelity (> 2.0, Fager 1963) to Station Group IV (i.e.,showed a strong association with this station group). Overall, invertebrate abundance was higher in the finest sediments. Polychaetes were the dominant taxon, making up 70% of individuals collected. Amphipods and bivalves were distributed across the species groups. The bivalves soft-shell clam (*Mya arenaria)* and blue mussel (*Mytilus edulis*) were two of the most abundant species (Table, 15-3, Fig. 15-4).

CURRENTS AND WAVES

Sediment transport processes and substrate characteristics in the jettied inlet of the Webhannet River and Wells Harbor were most recently studied by Rits (2003), who provides a thorough review of previous work related to harbor access and maintenance. His intensive sampling revealed fine sands in the inlet, harbor, and adjacent mainstem shoal areas, with grain size showing a down-gradient from deep areas toward the shallower salt marsh edge. Measurements of current velocity and wave height revealed that during high wave (i.e.,storm) conditions, flood velocities were increased by the jetty configuration, which led to the flood tide delivery of sediment into the inlet and harbor. In calm weather mean ebb current velocities in the jettied inlet were measured at 0.1 to 0.2 m s^{-1} greater than flood tide velocities along the northern side of the channel, while the reverse was true along the southern side of the channel, with differences between 0.2 to 0.4 m s^{-1}. This asymmetry would lead to the net landward sediment transport consistent with the shoaling history of Wells Harbor.

		Station Group			
Taxa Group		I	II	III	IV
A	*Streblospio benedicti*	803	61	43	12
	Capitella capitata	347	37	52	24
	Pygospio elegans	75	81	1068	1
	Oligochaeta	238	178	82	8
	Corophium volutator	14	96	10	1
	Mya arenaria	25	34	20	4
	Neanthes virens	9	13	2	2
	Polydora cornuta	12	17	3	<1
	Macoma balthica	2	2	0	0
	Gemma gemma	<1	9	1	<1
B	*Mytilus edulis*	28	3	5	47
	Littorina littorea	5	<1	0	1
	Balanus spp.	6	<1	0	0
	Monocorophium insidiosum	<1	<1	<1	0
C	*Paraonis fulgens*	4	13	65	80
	Tharyx sp. *A*	27	14	11	5
	Spiophanes bombyx	5	2	15	11
	Tellina agilis	1	<1	1	11
	Spisula solidissima	<1	<1	1	2
	Ampelisca abdita	7	5	2	1
	Nephtys caeca	<1	<1	0	<1
	Turbellaria	1	<1	0	<1
D	*Aricidea catherinae*	<1	<1	0	18
	Nemertea	<1	<1	<1	2
	Polygordius sp.	<1	0	0	2
	Leitoscoloplos robustus	<1	2	1	1
	Spio spp.	<1	<1	0	<1
	Eteone longa	<1	<1	0	<1
E	*Scolelepis squamata*	0	<1	0	8
	Protohaustorius deichmannae	0	<1	0	6

Table 15-3: Average abundance of taxa (individuals 0.04 m^{-2}) by station cluster group for Webhannet River (Diaz et al. 2005).

During flood tides, there is a strong phase correlation between wave heights and current velocities (R^2 > 0.75), so that these forces work in concert. During ebb tides, waves and current velocities are out of phase (R^2 > -0.75, Fig. 15-5). On the flooding tide, tidal currents are enhanced by wave-generated currents, boosting velocities by 25-40% under normal wave conditions, and by 100-150% under high wave conditions in the northern channel. In the southern, deeper side of the channel, the magnitude of this effect was reduced by half. On the ebb, tidal currents are retarded by wave generated currents, by 20-50% under normal conditions, and 75-125% under high wave conditions. This configuration of forces creates net landward movement of sediment. During hurricanes and Northeasters, it is possible that there would be no seaward sediment transport. The persistence of high waves after the storm surge would impede flushing of the storm-deposited material from the backbarrier. This hydrographic energy regime is not only relevant from the point of view of harbor maintenance, but also has significance for marsh erosion and accretion processes. Noticeable erosion of marsh banks facing the landward opening of the jettied inlet, and farther upstream along the southern main channel, may well be influenced by the interaction of jetties, waves, currents and sea-level rise (see photo). It is important to note, however, that preliminary analyses from state-required concurrent monitoring indicates that the pattern of marsh erosion and accretion appears to be similar before and after the dredging of Wells Harbor during late 2000 (Marvinney

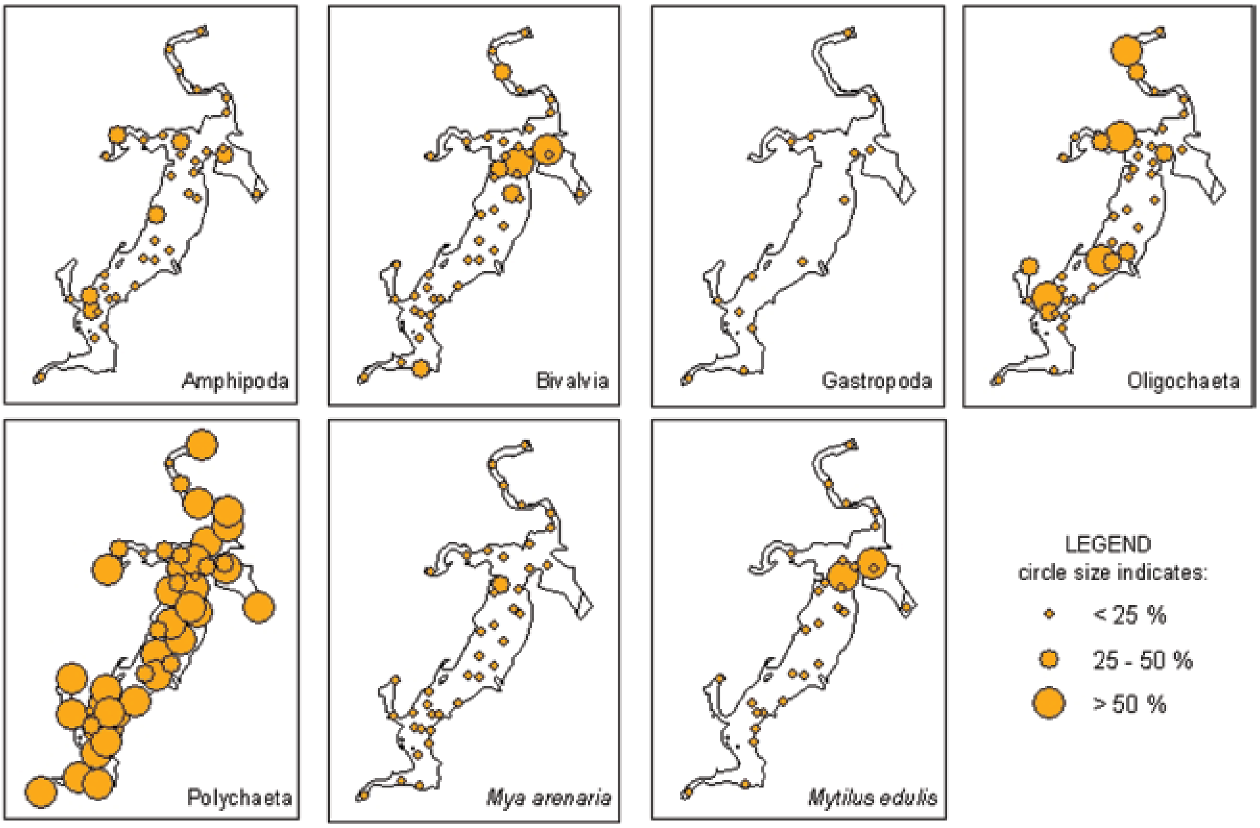


Figure 15-4: Percent abundance of selected invertebrate taxa in Webhannet benthic habitats.

An eroding bank in the Webhannet marsh. Photo Michele Dionne.

2002, 2003), with one exception. The northern portion of the main channel shows increased erosion since the dredge at several sites. This may be evidence of natural channel migration, but an effect due to dredging cannot be ruled out at this point. Final analyses of 7 years of monitoring data are forthcoming.

ICE

The plant communities on northern Gulf of Maine marshes are regularly subjected to disturbance by ice during the winter months. By freezing to the substrate at low tide, then floating free during high tide, or during ice-out in the spring, ice can lead to the removal of both plants and the surface layer of peat in which they root. A review of the effects of ice on tidal marshes indicates that ice disturbance on salt marshes increases from New England to the Gulf of St. Lawrence (Dionne 1989). Chmura *et al.* describe the distribution and abundance of *Plantago maritima* along the New Brunswick coastal reach from St. John to the Maine border as a distinct middle marsh zone. This pattern was observed as far

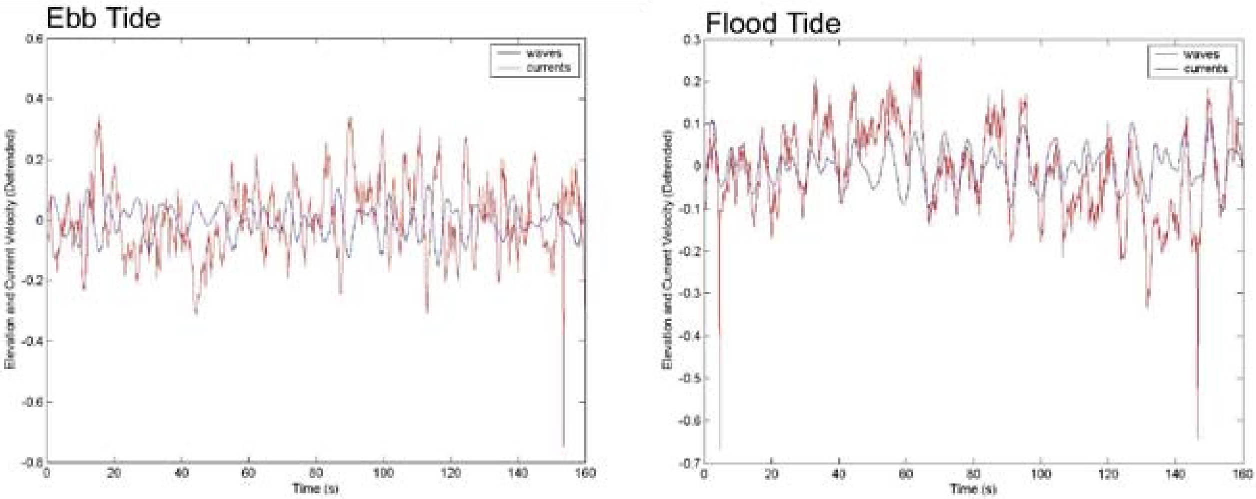


Figure 15-15: On the ebb tide in the Webhannet inlet, wave height and current velocity are out of phase, while on the flood tide, they are in phase, increasing sediment transport on the flood tide relative to that on the ebb (Rits 2003).

south as the Reserve's Little River estuary. They describe a pattern where stranded drift ice consolidates as shorefast ice at elevations bracketed by neap and spring high water. The ice mass moves up and down with the tides (see photo). The elevation of the ice-mediated erosion of the marsh edge corresponds to the elevation of the *Plantago* zone. Given that this species is known to be favored by to other types of disturbance (e.g. cattle grazing and mowing), Chmura *et al*. hypothesize that ice shearing acts to crop the *Spartina patens* turf, creating opportunity for *Plantago* colonization and persistent zone formation.

Field survey and experimental manipulations on the ice-disturbed marsh surface of the Reserve's Little River estuary reveal additional effects of ice on salt marsh plant communities (Ewanchuk and Bertness 2003). Ewanchuk and Bertness followed the recovery of 50 large ice-disturbances on the Little River high marsh from 1998 through 2001. Each disturbed area contained a central scar in which surface peat had been removed, surrounded by a halo of dead vegetation. Plant species were transplanted to a number of large ice-disturbed patches to determine species-specific abilities to recolonize these areas. An additional experiment improved drainage of soils in ice-disturbed areas by installing wicking material in the substrate to mimic plant evapotranspiration.

Ice cover downstream of Drakes Island Road on the Webhannet Marsh at low tide. Shorefast ice can be seen along channel edge in background. Photo Michele Dionne

Ice melting and depositing sediment on the marsh. Photo Michele Dionne.

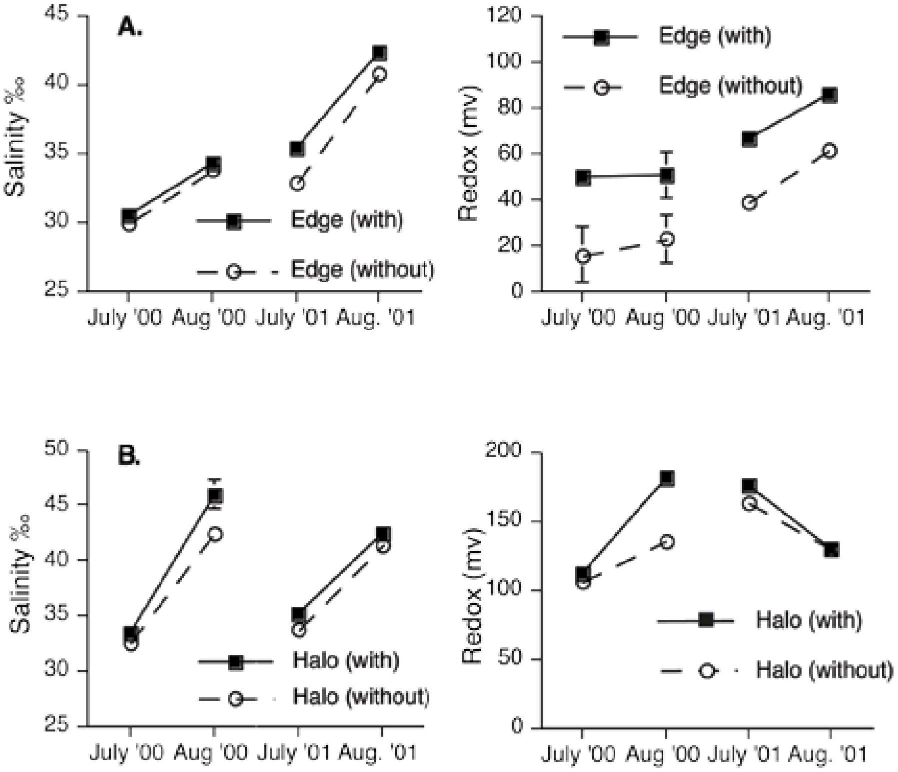


Figure 15-6: Soil salinities and redox potentials from soil moisture manipulation experiment (Ewanchuk and Bertness 2003). Plots in which moisture was reduced through wicking indicated as "with," plots with normal soil moisture indicated as "without." Results in A are from are from ice scar edge, results in B are from ice scar halo. Reproduced with kind permission of Springer Science and Business Media.

Wicking increased soil oxygen levels and resulted in 30% greater plant colonization (Fig. 15-6). After 4 years of recovery in the non-experimental ice-disturbed patches, the halo areas had returned to the surrounding species composition. In contrast, the ice scars remained relatively bare. Seedlings of glasswort (*Salicornia europea*) were just becoming established, along with vegetative ramets from adjacent smooth cordgrass (*Spartina alterniflora*) and spikegrass (*Distichlis spicata*), but still no evidence of other common salt marsh plants. Scar areas had higher water tables and lower soil redox potential (a measure of oxygen availability) than halos or undisturbed marsh. Glasswort was the only plant that survived transplantation to ice scars. Ice-disturbed patches generated harsh edaphic conditions (salinity and redox), which slowed patch recovery. Experimental results indicated that complete patch recovery likely involves secondary succession. Succession would involve improvement of soil conditions via evapotranspiration, mediated by stress-tolerant plant species (e.g. smooth cord grass).

Ice is not only a disturbance agent that influences plant zonation and succession, but also a vehicle for sediment deposition on the high marsh surface. Argow (2006) quantified the amount of ice-rafted sediment deposition occurring on four salt marshes from Mid-coast Maine to Cape Cod, including the Webhannet River marsh (Fig. 7, photo). More than 18,000 m^2 of high marsh surface were surveyed annually along 5 transects on the Webhannet over three years. The estimated amount of ice rafted sediment deposited on the marsh in 2003 was the equivalent of 0.33 mm layer over the entire marsh area. In 2004 the thickness of the layer was 0.25 mm, and in 2005, the layer was 0.20 mm thick. The majority of survey points receiving ice-rafted sediment were within 30 m of a tidal creek. Four types of sediment were described: peat blocks, sandy sediments, muddy sediments and algal sediments, characterized by the presence of an algal mat. Peat blocks were found in the fore marsh (along creeks) and back marsh (along the upland), while sandy sediments were most abundant in the central mid-marsh

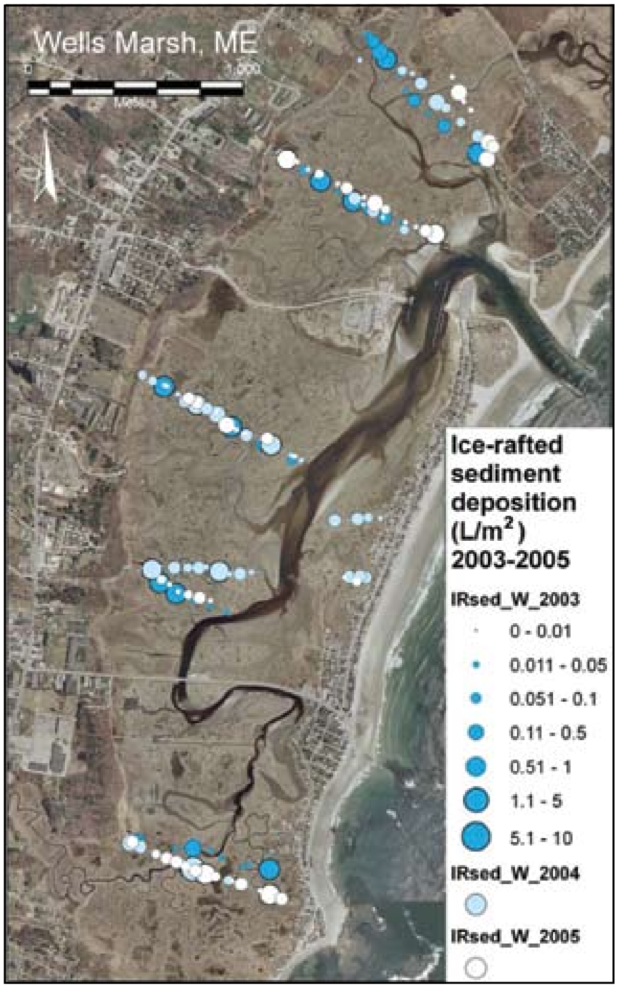


Figure 15-7: Volumes of ice-rafted sediment recorded along transects in the Webhannet marsh (Argow 2007).

Recording sediment depostion on the marsh (Argow 2007). Photo Britt Argow.

plain. Muddy sediments were common in the mid to foremarsh, while algal sediments were found in the mid to back marsh. The greatest volume of algal sediments occurred within 25 m of a marsh pool, and deposition of all sediment types decreased with distance from tidal creeks. The amount of ice-rafted sediment delivered to the marsh was similar to the amount of tidally deposited sediment measured in 2003 – 2004, 0.23 mm vs. 0.21 mm for ice and tides respectively, while in 2004-2005 tidally deposited sediment was 0.29 mm thick compared to 0.20 mm for ice. Ice rafting accounts for 50% of inorganic sediment deposition on the high marsh, and contributes to the hummocky surface of the marsh. This microtopographic variation may play an important role in reducing the impact of sea level rise on the persistence of the marsh.

REFERENCES

Argow, B.A. 2007. Winter processes of New England salt marshes. Dissertation, Boston University, Boston, MA. In press.

Begon, M., C.R. Townsend and J.L. Harper. 2006. Chapter 2: Conditions. *In* Ecology: from individuals to ecosystems. Blackwell, Malden, MA. pp. 32-48.

Bertness, M.D. and P.J. Ewanchuk. 2002. Latitudinal and climate-driven variation in the strength and nature of biological interactions in New England salt marshes. Oecologia 132: 392-401.

Bigelow, H.B. 1927. Physical oceanography of the Gulf of Maine. Bulletin of the Bureau of Fisheries. Bureau of Fisheries Document 969. 1027 pp.

Bulger, A.J., B.P. Hayden, M.E. Monaco, D.M. Nelson, M.G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. Estuaries 16(2): 311-322.

Caffrey, J.M. 2004. Factors controlling net ecosystem metabolism in U.S. estuaries. Estuaries 27(1): 90-101.

Charnov, E.L. and J.F. Gillooly. 2004. Size and temperature in the evolution of life histories. Integrative and Comparative Biology 44: 494-497.

Chmura, G.L., P. Chase and J. Bercovitch. 1997. Climatic controls of the middle marsh zone in the Bay of Fundy. Estuaries 20(4): 689-699.

Clarke, A. and K.P.P. Fraser. 2004. Why does metabolism scale with temperature? Functional Ecology 18(2): 243-251.

Crain, C.M., B.R. Silliman, S.L. Bertness and M.D. Bertness. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. Ecology 85(9): 2539–2549.

Dalton, C., F. Dillon, S.D. Bricker and M. Dionne. 2006. Synthesis of SWMP Data for ASSETS Eutrophication Assessment of the North Atlantic Region NERR Systems. Final report to CICEET (grant NA-04NOS4190109). 92 pp.

Diaz, R.J., R. Rowe, P. Wilbur, K. Schaefer, M. Dionne, R.A. McKenzie. 2005. Benthic habitat mapping project: Webhannet and York River estuaries. Report to National Oceanic and Atmospheric Administration Coastal Services Center, Charleston, SC. Wells National Estuarine Research Reserve, Maine. 68 pp.

Dionne, J.C. 1989. The role of ice and frost in tidal marsh development – a review with particular reference to Quebec, Canada. Essener Geographie Arbeiten 18: 171-210.

Ewanchuk, P.J. and M.D. Bertness. 2003. Recovery of a northern New England salt marsh plant community from winter icing. Oecologia 136: 616-626.

Ewanchuk, P.J. and M.D. Bertness. 2004a. Structure and organization of a northern New England salt marsh plant community. Journal of Ecology 92: 72-85.

Ewanchuk, P.J. and M.D. Bertness. 2004b. The role of waterlogging in maintaining forb pannes in northern New England salt marshes. Ecology 85(6): 1568-1574.

Fager, E.W. 1963. Communities of organisms. *In* The Sea. Volume 2 *Edited by* M. N. Hill. John Wiley and Sons, New York, New York.

Hacker, S.D. and M.D. Bertness. 1999. Experimental evidence for factors maintaining plant species diversity in a New England salt marsh. Ecology 80: 2064-2073.

Kelly, J.R. 1996. Dissolved oxygen in Maine estuaries and embayments. Maine Department of Environmental Protection and the Wells National Estuarine Research Reserve, Wells, ME. 74 pp.

Kelly, J.R. 1997. Final report on dissolved oxygen in Maine estuaries and embayments: 1996 results and analyses. Maine Department of Environmental Protection and the Wells National Estuarine Research Reserve, Wells, ME. 95 pp.

Marvinney, R. 2002. Review of monitoring data, Wells Harbor scientific review panel. Unpublished report. Maine Geological Survey, Augusta, ME. 5 pp.

Marvinney, R. 2003. Review of monitoring data, Wells Harbor scientific review panel. Unpublished report. Maine Geological Survey, Augusta, ME. 8 pp.

Milbury, C.A. 1997. The distribution of soft-shell clam *Mya arenaria* (Linnaeus) recruits with the Webhannet estuary, Wells, ME. Undergraduate Honors Thesis. University of New Hampshire, Durham, NH. 61 pp.

Monaco, M.E., S.B. Weisberg and T.A. Lowery. 1998. Summer habitat affinities of estuarine fish in US mid-Atlantic coastal systems. Fisheries Management and Ecology 5: 161-171.

Rand, T.A. 2000. Seed dispersal, habitat suitability and the distribution of halophytes across a salt marsh tidal gradient. Journal of Ecology 88: 608-621.

Rits, M. 2003. Wave-current interaction, sediment transport, and the responses of a jettied channel to dredging, Wells Inlet, Maine. Masters Thesis. Boston University, Boston, MA. 328 pp.

USEPA. 2000a. Aquatic life water quality criteria for dissolved oxygen (saltwater): Cape Cod to Cape Hatteras. Fact Sheet. EPA-822-R-00-012. United States Environmental Protection Agency Office of Water, Washington, DC. 1pp. available at http://www.epa.gov/waterscience/criteria/dissolved/dofacts.html

USEPA. 2000b. Ambient aquatic life water quality criteria for dissolved oxygen (saltwater): Cape Cod to Cape Hatteras. EPA-822-R-00-012. United States Protection Agency Office of Water, Washington, DC. 55 pp.

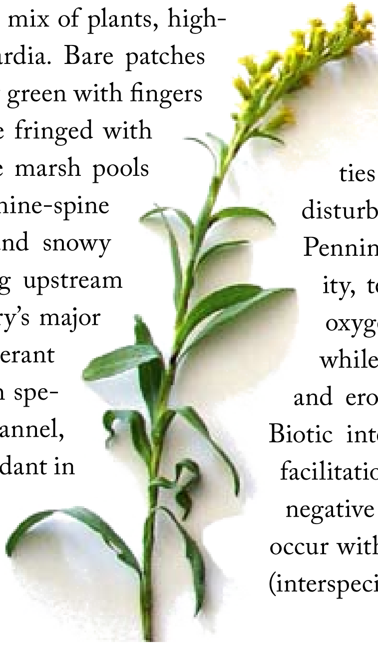
Ward, L.G. 2004. Variations in physical properties and water quality in the Webhannet River Estuary (Wells National Estuarine Research Reserve, Maine). Journal of Coastal Research 45: 39-58.

CHAPTER 16

Community Structure and Processes

MICHELE DIONNE

The salt marsh is a good place to bring those who question the importance of deterministic process and pattern in nature. Standing at the Reserve's Little River overlook, a single glance across the marsh at low tide confirms that this ecosystem is not the result of random events. Low marsh with its monoculture of smooth cordgrass (*Spartina alterniflora*), high marsh with its salt marsh hay (*Spartina patens*) and spike grass (*Distichlis spicata*), and the upland edge with its black rush (*Juncus gerardii*), form distinct layers within the tidal range (see photo next page). Forbe pannes dot the high marsh surface with a different mix of plants, highlighted by a border of seaside gerardia. Bare patches created by the winter's ice are bright green with fingers of glasswort. High marsh pools are fringed with the stunted form of cordgrass. The marsh pools harbor mummichogs, elvers and nine-spine sticklebacks - great blue herons and snowy egrets are having their fill. Gazing upstream toward the confluence of the estuary's major freshwater tributaries, the salt-tolerant plants give way to zones of brackish species. Walking out along the main channel, softshell clam siphon holes are abundant in the sandier substrates, while green crabs burrow among the plant stems at the marsh's muddier lower edge. When the tide comes in, they will be digging for clams. Periwinkle snails form grazing platoons along the marsh perimeter. Sanderlings pick amphipods from the fronds of seaweed wrack draped over sloping mud banks wherever the channel goes round a bend. Downstream, toward the fast-flowing inlet, blue mussels form reefs on the scoured channel bottom, where sea stars await the incoming tide to select their bivalve prey. This is an ecosystem that beckons ecologists to discover the invisible rules that govern its striking species patterns.



Community ecologists describe biological communities (i.e.,species patterns) and the underlying processes that create their structure. In the salt marsh, ecological communities are structured by abiotic conditions, physical disturbance, and biotic interactions (Bertness 1999, Pennings and Bertness 2001). In the salt marsh, salinity, temperature, flooding, nutrients and dissolved oxygen are the abiotic drivers of physical stress, while wrack, ice, sediment from storm overwash, and erosion are the primary sources of disturbance. Biotic interactions can take the form of competition, facilitation, predation and herbivory, and indirect negative effects (Begon *et al*. 2006). Biotic interactions occur within species (intraspecific) and between species (interspecific). For more than 3,500 years, these drivers

The Little River at mid-tide. Smooth cordgrass grows along the creek bank, with salt marsh hay forming the next zone. Photo Michele Dionne.

of community structure have maintained the Reserve's marshes as self-sustaining ecosystems (Kelley *et al.* 1995). Each of these drivers can be, and frequently are, altered directly or indirectly by human actions, with results that threaten the persistence of salt marsh ecosystems (Figs. 16-1, 16-2; Bertness *et al.* 2002, Bertness 2004). Major taxonomic communities studied by salt marsh ecologists include vascular plants, benthic invertebrates, insects, fish, and birds (Table 16-1). Bertness (1999) and Pennings and Bertness (2001) provide excellent reviews of salt marsh community ecology, much of it based on experimental field research. In the sections below, we draw from these reviews, and refer the reader to these sources for references to the primary literature.

Community Response to Abiotic Conditions

Tidal inundation

Maine's large tidal amplitude provides a wide vertical swath within which salt marsh plants establish. Tidal flooding determines the lower limit of plant growth, and smooth cordgrass (*Spartina alterniflora*) is the plant most tolerant of flooding. It is the sole plant species inhabiting the low marsh, which extends just below the elevation of mean sea level, and is submerged on every tide. Low marsh transitions to high marsh at the elevation of mean high water, and is flooded by the higher lunar tides – called spring tides. Smooth cordgrass is also found on the high marsh plain, in a stunted growth form, in waterlogged soils associated with salt marsh pools and other depressions in the high marsh surface, such as ice scrapes. Aquatic animals, too, must live by the tides,

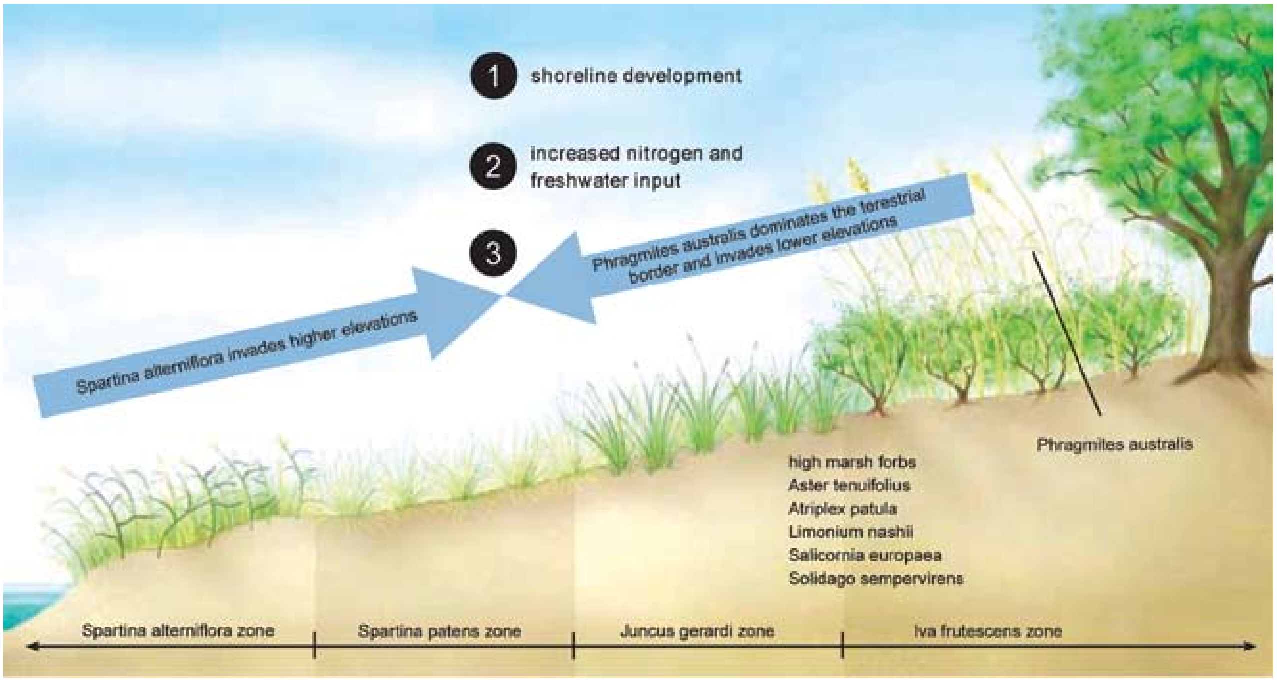


Figure 16-1: Four vegetation zones in a typical Gulf of Maine salt marsh (based on research in southern New England), and their response to adjacent upland development: 1) removal of shrubs and trees, 2) reduced salinity and increased nitrogen in marsh soils, and 3) encroachment of invasive species, alter marsh zonal boundaries (Bertness *et al.* 2004). © Emma Skurnick.

Typical plant zonation in a Gulf of Maine estuary (York River, York, ME) showing low marsh in foreground (smooth cordgrass), high marsh (salt marsh hay), and black rush (brown color) along upland edge. Photo Michele Dionne.

adjusting to the constant expansion and contraction of habitat according to the lunar cycle of neap and spring tides, or persisting in high marsh pools during the lower amplitude lunar tides – called neap tides. For example, in the fringing marshes of Casco Bay, Maine (just east of Wells NERR), benthic invertebrates were at considerably higher densities in the low marsh than the high marsh (by ≈ 50% on average, for 8 of 9 sites; Morgan *et al.* 2005).

Salinity

Tiner (1987) lists 163 species of Northeastern tidal marsh plants (Maine through Maryland, including plants from saline, brackish and tidal fresh marshes), a small fraction of the 2,096 species listed in the Flora of Maine (Haines and Vining 1998). These plants have in common their ability to physiologically tolerate the salt stress induced by variable soil salinities. In the Gulf of Maine, soil salinities are highest in the low marsh, following a decreasing gradient across the breadth of the marsh towards the upland edge, and along the length of the marsh towards the head of tide. Salinities vary spatially and temporally, depending on tidal amplitude, precipitation, and upland groundwater and surface water runoff. Modeling of common saline and brackish marsh plants (Konisky 2003, Konisky and Burdick 2004) based on growth experiments (with and without interspecific competition) across flooding and salinity gradients, indicate that plant communities will transform from brackish to salt-tolerant and back again. In these field experiments, plants responded to changes in salinity and flooding, with rapid response in the low marsh. This type of predictive modeling is highly applicable to hydrologic restoration of tidally restricted marshes.

Physical Disturbance

Ice is a unique and important agent of physical disturbance in Gulf of Maine marshes (see Chapter 15), creating bare scrapes with halos of dead vegetation on the high marsh surface, and an eroded zone along the low marsh - high marsh transition (see photo). On the Reserve's Little River marsh, only glasswort (*Salicornia europaea*) can successfully colonize ice scars, while spe-

Group	Flowering Plants	Birds	Fish	Invertebrates	Emergent Insects
Number of Known Species	93	≈ 132	57	288	43

Table 16-1: Species richness for selected taxonomic groups within Wells NERR estuarine communities.

An aerial view of the Little River marsh at the Reserve, showing forb pannes, high marsh pools, main channel with ice-eroded banks, and intertidal flats. Photo James List.

cies most tolerant of waterlogged soils (smooth cordgrass, and spike grass – *Distichlis spicata*) spread vegetatively from the perimeter (Ewanchuk 2003, Ewanchuk and Bertness 2003). Based on the state of recovery after four years, it likely takes a decade for these patches to complete succession and return to salt marsh hay (*Spartina patens*). The rate of recovery of these patches, referred to as forb pannes for their distinct community of forbs (herbaceous plants that are not grasses), appears to be influened by the annual hemiparasitc plant, seaside gerardia (*Agalinis maritima*). Seaside gerardia rings these forb pannes in late summer but does not colonize the panne interior. This plant is a root parasite, using the root systems of salt hay and black rush host plants for water and nutrients. When seaside gerardia was experimentally removed from panne borders, the encroachment of clonal turfs was increased by half over two growing seasons. By altering the rate at which forb pannes turn back to salt hay turf, this species plays an important role in determining salt marsh plant species richness and diversity.

Some marsh plants influence others through physical habitat modification (Crain and Bertness 2006). When seaside arrow grass (*Triglochin maritima*) occurs in forb pannes, it forms elevated rings with high plant cover, compared to the adjacent mostly bare, substrate (Fogel et al. 2004). In manipulative field experiments, four plant species performed better in raised mud substrate, where soils were less waterlogged. Arrow grass grown in the greenhouse increased the production of shallow roots in response to waterlogged soils, the potential mechanism of ring formation. This species and those it facilitates may increase in abundance if sea level rise leads to increased waterlogging stress.

Wrack is also abundant in Gulf of Maine salt marshes, due to the winter senesence of marsh vegetation. This dead above-ground biomass sloughs off with the tides over time, often helped by the shearing effects of ice. Wrack deposits on the high marsh can kill the underlying vegetation, initiating a process of secondary succession. Fugitive species invade the newly created space, the particular suite depending on the concentration of salt in the soils from evaporation in the absence of shading. In this case, only the most salt-tolerant species, glasswort (*Salicornia europaea*) can establish by seed, and one other species, spike grass (*Distichlis spicata*), can invade vegetatively with water supplied from clone mates established beyond the high salinity zone. The glasswort facilitates succession of less salt-tolerant fugitive plants that establish by seed (e.g. sea lavender – *Limonium nashii*, marsh orach – *Atriplex patula*, seaside goldenrod – *Solidago sempervirens*) by reducing soil salinities. Wrack can also facilitate the spread of the salt marsh invasive species, common reed (*Phragmites australis*: Minchinton 2002). When wrack was experimentally manipulated along the marsh perimeter, where it naturally becomes stranded, it smothered the underlying marsh turf, opening up space favorable to the dramatic spread of the common reed.

Nutrients

Salt marsh plants are generally limited by nitrogen, in that they increase their productivity when nitrogen is added experimentally. Ecologists, however, are not the only ones who add nitrogen to salt marshes. Contemporary development practices are transforming upland forested buffers into intensively managed lawns, golf turfs, etc. Shoreline development is a very strong predictor of common reed dominance (Fig. 16-2). The combined effect of increased nutrient applications and increased surface water runoff can dramatically enhance the spread of the invasive common reed (*Phragmites australis*). Until recently, this species was restricted by soil salinity to a narrow band around the marsh-upland perimeter. With lowered salinities and increased nitrogen, this plant becomes the competetive dominant on the high marsh, rather than salt hay and black rush. These plants are superior competitors for nitrogen when it is limited, but when it is not, common reed outcompetes these low turfs for light. It is now in the process of completely covering many salt marshes in southern New England, and is expanding in northern marshes (Bertness *et al.* 2002, Bertness 2004). To complicate matters, this invasive form of common reed appears to be a European strain, rather than the native New England strain (Saltonstall 2002). With increased nitrogen, the transition from salt hay to smooth cordgrass is also altered, since cordgrass can outcompete salt hay when released from competition for this nutrient. Habitats dominated by common reed have reduced abundances of fish and benthic invertebrates (Able *et al.* 2003, Raichel *et al.* 2003, Osgood *et al.* 2003, Morgan *et al.* 2005).

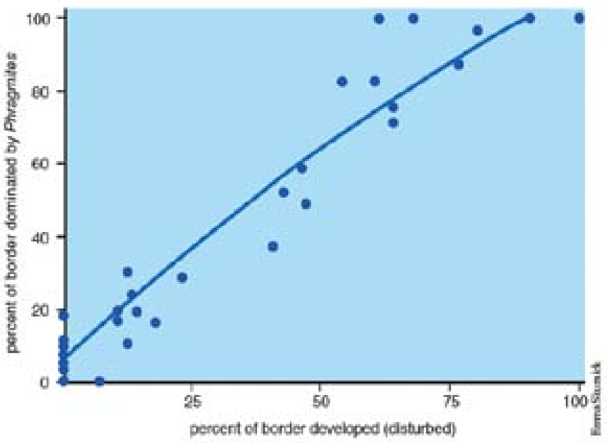


Figure 16-2: Bertness *et al.* (2004) found a strong relationship between shoreline development and invasive *Phragmites* percent cover in New England salt marshes. © Emma Skurnick.

COMMUNITY RESPONSE TO BIOTIC INTERACTIONS

Competition and Facilitation

The upper limit of the smooth cord grass in the low marsh is determined by competition with the high marsh dominant plant, salt marsh hay (*Spartina patens*), operating within the sharp stress gradient at the elevation of mean high water. Below this elevation, salt marsh hay cannot withstand the flooding stress, but above this elevation, salt marsh hay outcompetes cordgrass, establishing the zonal boundary between low and high marsh. At the marsh's upland edge, a similar process limits the extent of salt marsh hay. Here, the black rush (*Juncus gerardi*), is unable to survive at the elevation of the salt hay meadow due to physical stress, but prevents salt hay from expanding into the black rush zone through interspecific competition. In fact, smooth cordgrass grows better at the elevation of the high marsh, when allowed to grow in the absence of competition from salt hay. Likewise, salt hay grows better at the elevation of the black rush zone, in the absence of competition from the zonal dominant.

In contrast to the insights we have gained from many elegant experimental studies of marsh plant competition (both interspecific and intraspecific), there is little evidence that animal species distributions within marsh-estuarine ecosystems are the result of competition. This may be due to the limited research effort devoted to this topic, or it may reflect a scenario that has been observed in other systems, where small mobile animals associated with dominant space holders are limited by stress, food availability, and / or predation.

Herbivory

Salt marshes are New England's native grasslands, and they support considerable primary production, much of which is consumed as detrital organic material. Herbivores do have a role to play, however, and can influence plant community structure through consumption of living plant biomass. A series of experiments using plants and herbivores at / from ten sites (Wells NERR in Maine to the Sapelo Island NERR in Georgia) identified strong latitudinal differences in plant palatability, leaf toughness, and nitrogen content (Fig. 16-3). Thirteen herbivore species had consistently higher consumption rates when feeding on northern vs. southern individuals for ten salt marsh plant species. Results support the hypothesis that salt marsh plants have evolved anti-herbivore defenses at lower latittudes, in the face of much higher herbivore pressure (Pennings *et al.* 2001, Pennings and Silliman 2005, Salgado and Pennings 2005). Research is currently under way to investigate herbivore-induced defenses in smooth cordgrass from north to south. Although herbivorous insects and decapods are unlikely to alter the zonal patterns of the salt marsh plant community, they may be important in the distribution and abundance of the many rarer species, through consumption not only of leaf tissue, but flowers and seeds as well. Beetles can prevent glasswort (*Salicornia europaea*), seaside goldenrod (*Solidago sempervirens*), and marsh orach (*Atriplex patula*), from colonizing bare patches. These plants need to be surrounded by less palatable species to persist in the marsh. A similar example of defense through association has been described for brant herbivory on seaside arrow grass (*Triglochin maritimum*), in England.

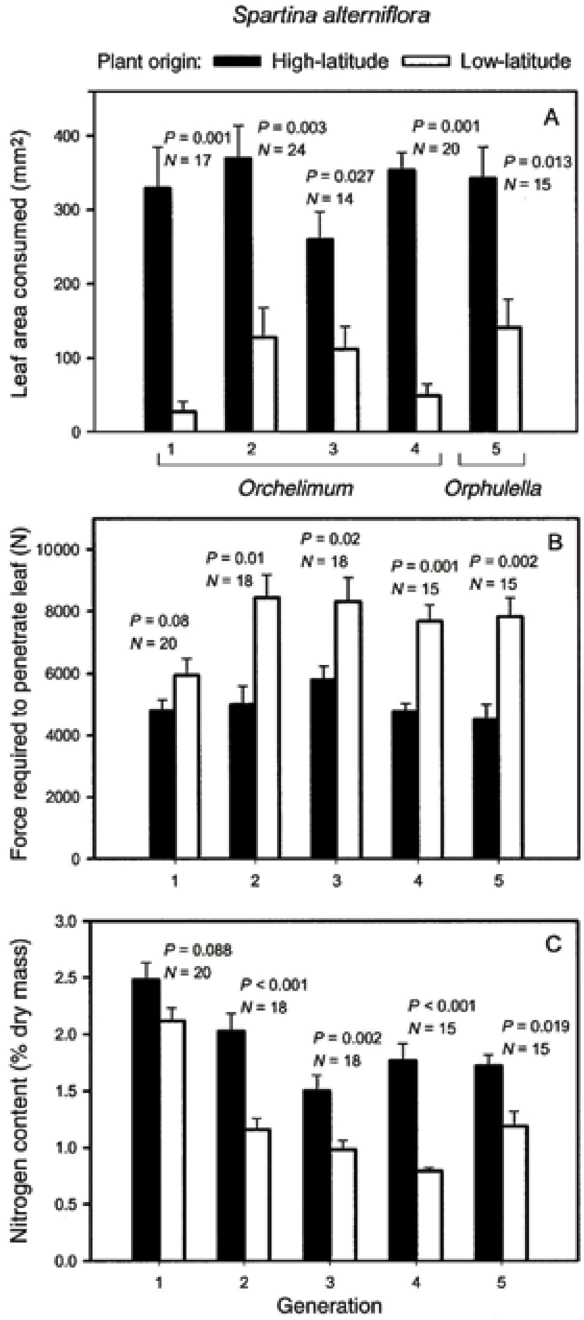


Figure 16-3: Salgado and Pennings (2005) conducted feeding trials by common insect herbivores on smooth cordgrass. Results supported their hypothesis that plants from southern marshes have evolved more effective anti-herbivore defenses than those from northern marshes, due to greater selective pressure. Reproduced courtesy of Ecological Society of America.

Canada geese, and brant geese (much less abundant now than historically), muskrats, and the common periwinkle (*Littorina littoraea*) also consume living plant material in Gulf of Maine tidal marshes, but the community level ef-

Grass shrimp and mummichogs seined from a marsh pool on the Webhannet River. Photo Michele Dionne.

fects of these grazers remain to be explored. The Canada goose was found to prefer plants with higher nitrogen content, among species lacking chemical defenses, but chemical defenses had a greater influence on goose foraging (Buchsbaum *et al*. 1984, Buchsbaum and Valiela 1987). Migrating flocks of Canada geese can create large disturbed areas through their rough foraging technique. These disturbances can initiate secondary succession, the outcome of which is further influenced by nutrient additions from goose droppings, and reduced plant litter. Snow goose grazing on dominant turf species in subarctic Canada maintains entire marshes in an early stage of succession, due to the greater tolerance to herbivory of early successional grasses. In fact, goose herbivory increases productivity of these species through thinning and fertilization.

Predation

Fish, birds and crustaceans are important predators in salt marsh systems, and they can have a strong influence on prey distribution and abundance. Shrimp and mummichogs are abundant and can restrict many small substrate-dwelling invertebrates to higher and more heavily vegetated marsh areas. Similar patterns are true for larger fish and crab predators. In marsh systems with many creeks and channels, larger aquatic predators patrol the marsh edge, restricting their prey to the higher areas of vegetated marsh, where thick vegetation and shorter periods of inundation reduce predator-prey encounters. In the York River, Virginia, interior marsh habitats contained greater numbers of resident mummichog (*Fundulus heteroclitus*) and striped killifish (*Fundulus majalis*) than did edge habitats (Cicchetti 1998). Conversely, prey consumption by transient marsh nekton (i.e.,blue crab, *Callinectes sapidus*) was threefold greater in edge compared to interior habitat. In the Gulf of Maine, larger predators along the marsh edge include piscivores such as the striped bass, and the non-native green crab, while large wading birds such as the great blue heron and the snowy egret forage heavily on fish and shrimp in high marsh pools. Wading birds most likely restrict foraging time for these prey species. Pool fish consistently hide under the overhanging pool edge when they detect the approach of a wading ecologist.

Fish and shrimp distributions in the marshes of the North Inlet-Winyah Bay NERR in South Carolina depend on life history (resident or transient), body size, and the presence of other taxa (Bretsch 2005). When fish were sampled in intertidal creeks on the incoming tide at 10 cm depth increments, fish species followed a consistent sequence of peak abundance, with depth. Shrimp (*Palaeomonetes* spp., *Litopenaeus setiferus*), mummichog, striped killifish, mullet (*Mugil* spp.) entered the creeks at < 40 cm depth. At 30-70 cm depth, spot (*Leiostomus xanthurus*), pinfish (*Lagodon rhomboides*), and spotfin mojarra (*Eucinostomus argenteus*) joined the community. Anchovy (*Anchoa* spp.) and Atlantic silversides (*Menidia menidia*) did not show a specific depth association, but typically entered when depth was > 20 cm. The general pattern of arrival was residents followed by transients followed by planktivores. Depth of migration for spot and mullet were a function of size, and as young-of-year of other species grew, their depth of migration also increased. There were many positive associations of species pairs, but negative density associations were apparent between the pinfish and the grass shrimp (*Palaeomonetes pugio*), and large mummichogs. The spotfin mojarra showed the same negative associations with the grass shrimp, and with both small and large mummichogs. In laboratory depth choice experiments with five species (grass shrimp, mummichog, white mullet, spot and pinfish), all species selected intermediate (40 cm) or maximum (60 cm) depths when tested alone. When tested all together, mummichogs and grass shrimp moved to the shallow depth (20 cm). When mullet and pinfish were paired against grass shrimp separately, they had no effect on shrimp depth selection, by when together, shrimp moved to the shallow depth. Further investigation of depth habitat partitioning observed in both field and lab may reveal reduced predation risk or increased foraging efficiency for certain species.

While the effect of green crab predation on tidal flat benthic infauna (especially the softshell clam) has been investigated at Wells NERR (Whitlow 2002, 2003), green crab predation on fish and invertebrates within the vegetated marsh has yet to be quantified (but see description of ongoing green crab studies in Chapter 9). Given their great biomass and large average size (pictured) in the vegetated marsh during flood conditions, and aggressive behavior, it is likely that this species is having a large impact on benthic and epibenthic invertebrates, fish and shrimp communities. Interestingly, the southward distribution of the green crab is itself limited by predation from the blue crab (deRivera *et al*. 2005). In Maine, green crabs have contributed to the decline of softshell clams (*Mya arenaria*). Clams respond to green crabs by burrowing deeper in the sediment. When clams were prevented from doing so experimentally, they suffered greater predation (Whitlow 2002, 2003). As such, burrowing behavior can be considered an inducible defense, and this response could be managed to protect them from predation by using predator chemical cues. Field and lab experiments revealed that clams responded to green crab chemical cues by burrowing deeper and growing longer siphons with greater mass. However, this response comes at a cost to the individual. Clams that survived by burrowing deeper had slower body growth rates, potentially the result of resource allocation to siphon growth and / or less efficient filter feeding. As on the marsh surface, green crabs in tidal flats have both a direct predatory and an indirect non-lethal effect on their prey.


Green crab, Carcinus maenas, an invasive species at Wells NERR. Photo Michele Dionne.

HUMAN INFLUENCES ON SALT MARSH COMMUNITIES

The Little River marsh is a rare example of a Gulf of Maine salt marsh that has been minimally altered by direct human action, whereas the Webhannet marsh has been subject to the typical array of alterations. The great majority of Gulf of Maine marshes are hydrologically fragmented by road crossings, transforming upstream sections from salt marsh to brackish or fresh marsh dominated by invasive plants (common reeed, salt marsh cattail – *Typha angustifolia*, and / or purple loosestrife – *Lythrum salicaria*). Nutrients and freshwater are increasingly available from changes in upland land use, altering the outcome of plant competition, increasing the spread of invasive plants, and changing marsh zonation. During the past 3,000 – 4,000 year history of Gulf of Maine salt marshes, marsh plant peat formation has increased marsh elevation apace with sea level rise. In the current day, rapid sea level rise may exceed upward marsh growth, transforming high marsh to low marsh, or ultimately, drowning the marsh altogether.

REFERENCES

Able, K.W., M. Hagan and S. A. Brown. 2003. Mechanisms of marsh habitat alteration due to *Phragmites*: response of young-of-the-year mummichog (*Fundulus heteroclitus*) to treatment for *Phragmites* removal. Estuaries 26(2B): 484-494.

Begon, M., C.R. Townsend, and J.L. Harper. 2006. Part 2: Species interactions in ecology: from individuals to ecosystems. Blackwell, Malden, MA. pp. 225 -409.

Bertness, M.D. 1999. Process and pattern in shoreline communities. *In* M. Bertness, The ecology of atlantic shorelines. Sinauer, Sunderland, MA. pp 135-176.

Bertness, M.D., P.J. Ewanchuk, and B.R. Silliman. 2002. Anthropogenic modifications of New England salt marsh landscapes. Proceedings of the National Academy of Sciences (USA) 99: 1395-1398.

Bertness, M.D. 2004. Salt marshes under siege. American Scientist 92: 54-61.

Bretsch, K. P. 2005. Nekton behavior in salt marsh intertidal creeks: patterns and mechanisms of tidal movement. Dissertation, University of South Carolina, Columbia, SC. 130 pp.

Buchsbaum, R., I. Valiela, and T. Swain. 1984. The role of phenolic compounds and other plant constituents in feeding by Canada geese in a coastal salt marsh. Oecologia 63: 343-349.

Buchsbaum, R., and I. Valiela. 1987. Variability in the chemistry of estuarine plants and its effect on feeding by Canada geese. Oecologia 73: 146-153.

Crain, C.M. and M.D. Bertness. 2006. Ecosystem engineering across environmental gradients: implication for conservation and management. BioScience 3: pp. 211-217.

deRivera, C.E., G.M. Ruiz, A. H. Hines, and P. Jivoff. Biotic resistance to invasion: native predator limits abundance and distribution of an introduced crab. Ecology 86(12): 3364-3376.

Cicchetti, G. 1998. Habitat use, secondary production, and trophic export by salt marsh nekton in shallow waters. Dissertation, College of William and Mary, Williamsburg, VA.

Ewanchuk, P.J. 2003. Ecology of northern New England salt marsh plant communities. Dissertation. Brown University, Providence, RI. 175 pp.

Ewanchuk, P.J., and M.D. Bertness. 2003. Recovery of a northern New England salt marsh plant community from winter icing. Oecologia 136: 616-626.

Fogel, B.N., C.M. Crain and M.D. Bertness. 2004. Community level engineering effects of *Triglochin maritima* (seaside arrowgrass) in a salt marsh in northern New England, USA. Journal of Ecology 92: 589-597.

Haines, A. and T.F. Vining. 1998. Flora of Maine: a manual for identification of native and naturalized vascular plants of Maine. V. F. Thomas Co., Bar Harbor, ME. 847 pp.

Kelley, J.T., W.R. Gehrels, and D.F. Belknap. 1995. Late Holocene relative sea-level rise and the geological development of tidal marshes at Wells, Maine, U.S.A. Journal of Coastal Research 11(1): 136-153.

Konisky, R.A. 2003. Spatial modeling and visualization of habitat response to hydrologic restoration in New England salt marshes. Dissertation. University of New Hampshire, Durham, NH. 305 pp.

Konisky, R.A., and D. Burdick. 2004. Effects of stressors on invasive and halophytic plants of New England salt marshes: a framework for predicting response to tidal restoration. Wetlands 24(2): 434-447.

Minchinton, T.E. 2002. Disturbance by wrack facilitates spread of *Phragmites australis* in a coastal marsh. Journal of Experimental Marine Biology and Ecology 281: 89-107.

Morgan, P.A., M. Dionne, R. Mackenzie, and L. Cerci. 2005. Ecological functions and values of fringing salt marshes susceptible to oil spills in Casco Bay, Maine. Report to Maine Oil Spill Advisory Committee, Maine Sea Grant, Oromo, ME. 67 pp.

Osgood, D. T., D. J. Yozzo, R. M. Chambers, D. Jacobson, T. Hoffman, and J. Wink. 2003. Tidal hydrology and habitat utilization by resident nekton in *Phragmites* and non-*Phragmites* marshes. Estuaries 26(2B): 522-533.

Pennings, S.C., E.L. Sitka, and M.D. Bertness. 2001. Latitudinal differences in plant palatability in Atlantic coast salt marshes. Ecology 82(5): 1344-1359.

Pennings, S.C. and M.D. Bertness. 2001. Salt marsh communities. *In* Marine community ecology. *Edited by* M. D. Bertness, S.D. Gaines, and M.E. Hay. Sinauer Associates, Sunderland, MA. pp 289-316.

Penning, S.C., and B.R. Silliman. 2005. Linking biogeography and community ecology: latitudinal variation in plant-herbivore interaction strength. Ecology 86(9): 2310-2319.

Raichel, D.L., K.W. Able, and J.M. Hartman. 2003. The influence of *Phragmites* (common reed) on the distribution, abundance, and potential prey of a resident marsh fish in the Hackensack Meadowlands, New Jersey. Estuaries 26(2B): 511-521.

Salgado, C.S. and S.C. Pennings. 2005. Latitudinal variation in palatability of salt-marsh plants: are differences constitutive? Ecology 86(6): 1571-1579.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. Proceedings of the National Academy of Sciences (USA) 99: 2445-2449.

Tiner, R. W. 1987. A field guide to coastal wetland plants of the Northeastern United States. University of Massachusetts Press, Amherst, MA. 286 pp.

Whitlow, W.L. 2002. Changes in native species after biological invasion: effects of introduced green crabs on native soft-shell clams and an estuarine community. Dissertation. University of Michigan, Ann Arbor, MI. 310 pp.

Whitlow, L., N.A. Rice, and C. Sweeney. 2003. Native species vulnerability to introduced predators: testing an inducible defense and a refuge from predation. Biological Invasions 5: 23-31.

CHAPTER 17

Biological Productivity

MICHELE DIONNE

> *Estimating production in natural populations is not easy under the best of conditions, but when the populations are mobile and the boundaries of the system are open and ill-defined, the task is formidable indeed.*
> *– R. T. Kneib* [1]

As described in previous chapters, the Reserve's estuaries are extremely dynamic systems, with impressive variation in basic abiotic parameters on daily and seasonal time scales. Variation in water depth, and hence available habitat for aquatic organisms, varies dramatically over daily and monthly tide cycles in these macrotidal systems. These patterns of variation do not prevent Gulf of Maine marsh-estuarine ecosystems from long-term sustainability or substantial productivity. They do, however, present great challenges to those who would measure the production and movement of energy through salt marsh food webs (Fig. 17-1). Salt marsh emergent vegetation is the dominant source of photosynthetically produced organic matter (i.e.,primary production), but benthic microalgae (e.g. diatoms, blue green algae and other taxa that grow on sediments or vascular plant surfaces) and phytoplankton also have a role to play. Many species of consumers obtain their energy from a mix of these sources, depending on their ontogeny, morphology and life history. Salt marsh primary consumers are mostly small benthic invertebrates (both meiofauna and macrofauna), epibenthic macrofauna, and bivalve filter feeders. Secondary consumers are primarily juvenile nektonic (e.g. free-swimming), crustaceans and fish, while tertiary level consumers are piscivorous fish and birds. The nekton display three general life history patterns with regard to marsh-estuarine habitats (Fig. 17-2). Marsh **residents** spend their entire lives in the estuary.

Research Associates Jeremy Miller (left) and Michael Haas sample fish from a marsh pool with lift nets. Photo Wells NERR.

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[1] Kneib, R.T. 2000. Salt marsh ecoscapes and production transfers by estuarine nekton in the southeastern United States. *In* Concepts and controversies in tidal marsh ecology. *Edited by* M.P. Weinstein and D.A. Kreeger. Kluwer, Boston, MA. pp. 267-291.

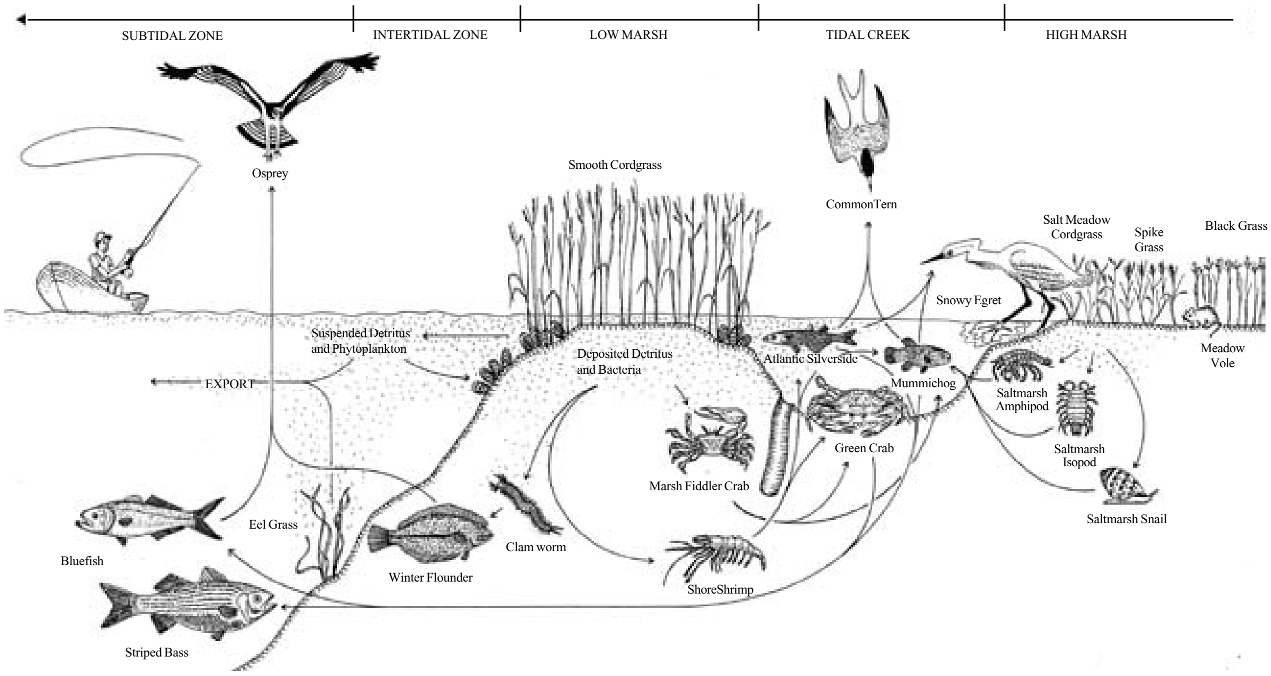


Figure 17-1: Diagram of a Gulf of Maine marsh-estuarine food web. Source Thomas Oulette.

Marsh **transients** spawn in marine waters, spend their larval and juvenile period in the estuary, and forage in the estuary as adults. **Migratory** fish pass through the estuary on their way to and from their spawning habitats – from marine to freshwater to spawn for **anadromous** fish, and from freshwater to marine for **catadromous** fish (of which the American eel – *Anguilla rostrata* is the only example in the Gulf of Maine).

Salt marsh nekton abundance follows pulses driven by reproduction, mortality and circadian rhythms of activity. These pulses in nekton abundance likely drive corresponding pulses in prey abundance (top down processes), and in the export of production from the marsh (bottom-up processes; Kneib 1997a,b; Kneib 2000). Most of what we know about the trophic transfer of marsh primary production comes from marsh-estuarine systems to the south of the Gulf of Maine, that are increasingly dominated by low marsh habitat along the southward latitudinal gradient. Conversely, the vegetated surface of the Reserve's Webhannet marsh is only 7% low marsh habitat. Current models of low marsh production and food web structure from more southerly systems wait to be tested in the Gulf of Maine.

In southern marshes, many transient nekton species regularly travel short distances from edge to interior marsh habitat (< 5m), leaving much of the available flooded habitat unused. The marsh edge is a hotspot for fish abundance in these systems (Kneib and Wagner 1994, Kneib 2000). The importance of edge in New England high marsh systems has yet to be demonstrated, and it is useful to note that the structure of the interior salt hay marsh is very different from that of the flooded smooth cordgrass marshes farther south. On a good spring tide, marine transients (e.g. fish and crustaceans that sometimes are found offshore) may swim over the submerged turf of the typical salt hay meadow more easily than they could through the palisades of submerged cordgrass in southern marshes. This may be especially true in the first half of the growing season, before salt hay achieves peak biomass and height. Marine transient use of vegetated marsh habitats may be greater on the spring tides in the Gulf of Maine. Marsh resident fish in southern marshes enter the vegetated marsh earlier on the flood tide and retreat back to the creeks late on the ebb tide, using more of the available habitat over a longer time period than transient fishes.

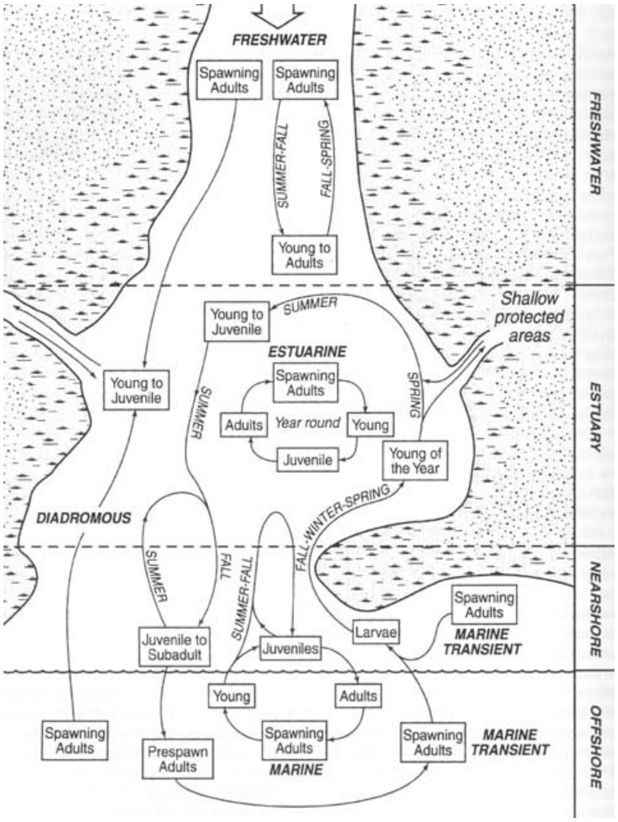


Figure 17-2: Habitat use patterns of nekton in marsh-estuarine ecosystems according to life-history stage (Deegan et al. 2000). Reprinted with kind permission of Springer Science and Buisness Media.

SECONDARY PRODUCTION, FOOD WEBS, AND HABITAT

Salt marsh emergent vegetation produces large amounts of organic matter every growing season, but this living plant biomass is not directly consumed by nekton (Kneib 1997a). Marsh nekton prey heavily on small benthic and epibenthic invertebrates, and these members of the marsh food web likely ingest vascular plant detritus and associated microbial detritivores, as well as benthic microalgae (Bell and Coull 1978, Guidi 1984, Couch 1989, Nelson and Coull 1989, Newell and Barlocher 1993, Newell and Porter 2000). Analysis of stable isotope signatures is a useful tool for teasing apart the sources of primary production contributing to individual consumer biomass. The rare heavy stable isotopes of carbon (^{13}C), nitrogen (^{15}N), and sulfur (^{34}S) are commonly used in marsh-estuarine food web analysis as the normal weight forms of these elements are important components of living biomass. The heavy isotopes react at different rates than the lighter forms, leading to characteristic variations in the ratio of heavy to light isotopes among groups of primary producers. The convention for measuring isotopic composition of a sample is:

$$\delta X = [(R_{sample}/R_{standard}) - 1] \cdot 10^3,$$

where X = ^{13}C, ^{15}N, or ^{34}S and R = $^{13}C/^{12}C$, $^{15}N/^{14}N$, or $^{34}S/^{32}S$.

Isotope ratios can also vary across trophic levels. For example, $^{15}N/^{14}N$ is enriched by ≈ 3% from primary producer to primary consumer Evidence from studies using stable isotopes as tracers of primary production demonstrates that this organic matter contributes to the biomass of resident and transient nekton (Deegan and Garritt 1997, Kwak and Zedler 1997, Patterson and Whitfield 1997, Currin *et al.* 2003, Litvin and Weinstein 2003).

MARSH-ESTUARINE-NEARSHORE TROPHIC RELAY

A number of authors have suggested that marsh-estuarine ecosystems export energy to nearshore waters through the emigration of fish (Bozeman and Dean 1980, Odum 1980, Weinstein *et al.* 1980, Wiegert and Pomeroy 1981, Currin *et al.* 1984, Deegan and Thompson 1985, Zijlstra 1988, Rountree 1992). Kneib (1997a, 2000) outlined a mechanism to explain the transfer of primary production in the vegetated marsh to nekton in the open estuary, which again is based largely on studies of southern marshes. He describes a trophic energy relay, with fish partitioning marsh habitat according to body size and predation risk. The smallest resident fishes and shrimp occupy the vegetated marsh, using water filled microhabitats at low tide, and feeding on invertebrates. As they outgrow their low tide refugia (≈ 15 mm total length), they begin to migrate into the shallowest tidal

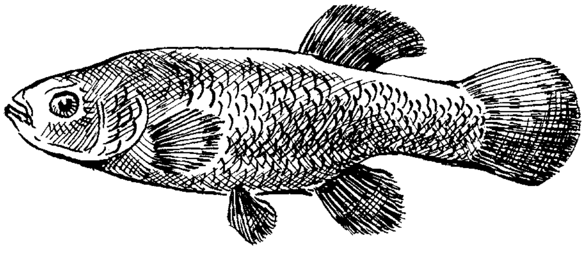
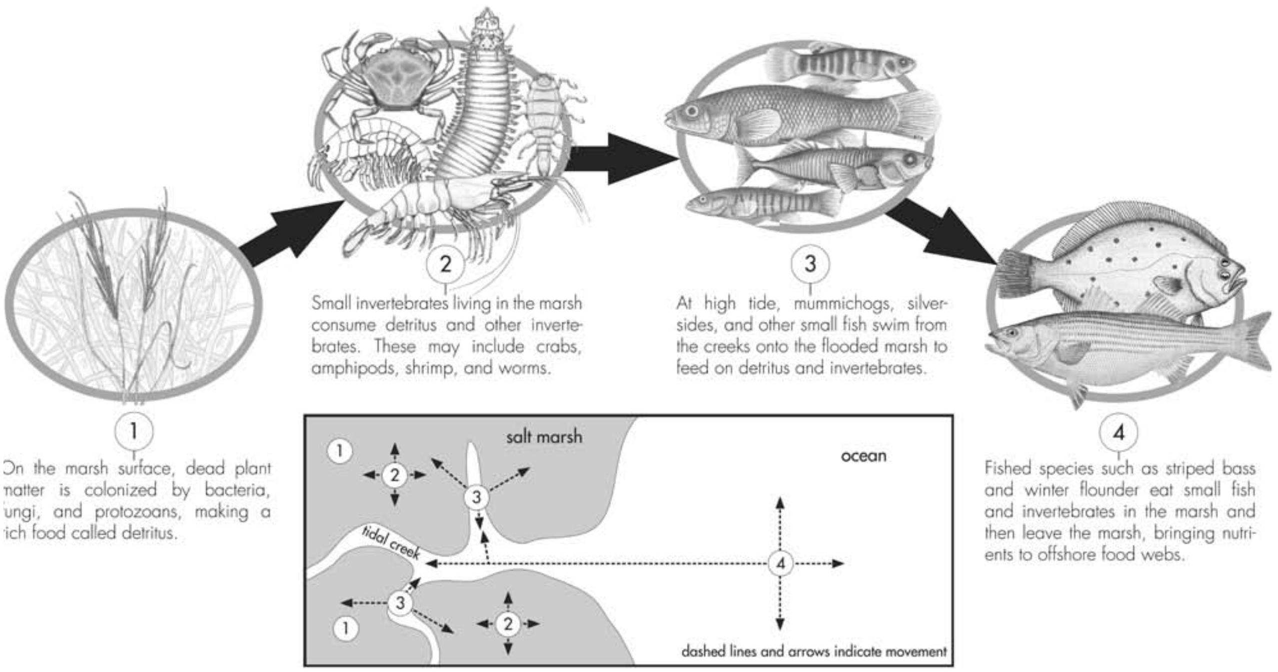


Figure 17-3: Mummichog, *Fundulus heteroclitus*. Source Robert Shetterly.

creeks with the adults at low tide, where predation risk is greater, especially at low tide. Here the energy from primary production moves up one level in the trophic web, and takes one spatial step closer to the open estuary. In the shallow intertidal creeks migrating resident fish excrete / egest unassimilated organic matter ingested during high tide forays to the vegetated marsh. Adult marsh residents (e.g. mummichog, Fig 17-3) overlap with juvenile transient predators in deeper creeks and channels, and the energy from the primary producers is relayed up to the next trophic level and further down the estuary's drainage network. As these transient predators grow, they move to the deeper water of the open estuary and coastal ocean, bringing with them the energy produced within the vegetated marsh (Fig. 17-4). In the Reserve's estuaries, tomcod (*Microgadus tomcod*), American eel (*Anguilla rostrata*), striped bass (*Morone saxatilis*), bluefish (*Pomatomus saxatilis*), and dogfish (*Squalus acanthius*) are examples of species that could perform this role. Some species, such as the Atlantic silverside *(Menidia menidia)* participate in the trophic relay at every level. The silverside spawns in the vegetated marsh (Middaugh 1981), inhabits the shallowest to the deepest portions of the marsh-estuarine system, depending on life history stage, and emigrates seasonally to the coastal ocean as an adult (Conover and Murawski 1982).

In New Jersey marsh creeks, tidal dynamics were also considered in the foraging and movement of the summer flounder (*Parlichthys dentatus*, Rountree and Able 1992). Juvenile summer flounder captured while leaving marsh creeks on the ebb tide had fuller guts than those captured while entering creeks on the flood tide, suggesting that this species uses tidal migration as a foraging strategy to feed in marsh creeks. Atlantic silverside, mummichog, marsh grass shrimp (*Palaemonetes vulgaris*), and sand shrimp (*Crangon septemspinosa*) were the most abundant prey. On the ebb tide, summer flounder fecal deposits and mortality through predation contribute marsh derived energy to the open estuary. Estimates of migration rates using tagged fish in July showed that summer flounder continued to use creek habitat during August through October. When these fish make their seasonal migration to shelf waters, their biomass includes the energy derived from tidal creek feeding. Deegan *et al.* (2000) describe this study as an example of multiple trophic relays, cyclic tidal relays between marsh creek and bay, and ontogenetic (i.e.,governed by individual development and growth) seasonal relays from marsh and bay to marine waters.

In low marsh habitat of the Chesapeake Bay NERR, Cicchetti and Diaz (2000) measured nekton export of marsh-produced prey species to deep water from several marsh habitats over a 150-day sampling period. Blue



Small invertebrates living in the marsh consume detritus and other invertebrates. These may include crabs, amphipods, shrimp, and worms.

At high tide, mummichogs, silversides, and other small fish swim from the creeks onto the flooded marsh to feed on detritus and invertebrates.

On the marsh surface, dead plant matter is colonized by bacteria, ungi, and protozoans, making a ich food called detritus.

Fished species such as striped bass and winter flounder eat small fish and invertebrates in the marsh and then leave the marsh, bringing nutrients to offshore food webs.

Figure 17-4: Diagram of estuarine trophic relay. Figure Ethan Nedeau, Biodrawversity.

Marsh Zone		Unvegetated Habitat	Marsh Edge	Marsh Fringe	Marsh Interior
Percent of day inundated by tides.		89%	55%	32%	15%
Animal prey exported from marsh per 150 days	Blue Crabs	1.8-2.1 gdw m^{-2}	6.2 gdw m^{-2}	2.5 gdw m^{-2}	1.3 gdw m^{-2}
		3-6.4 inds m^{-2}	20.3 inds m^{-2}	6.0 inds m^{-2}	2.7 inds m^{-2}
	Transient Fishes	0.3 gdw m^{-2}	0.4 gdw m^{-2}	0.1 gdw m^{-2}	0.04 gdw m^{-2}
		9.2 inds m^{-2}	0.9 inds m^{-2}	0.2 inds m^{-2}	0.1 inds m^{-2}

Table 17-1: Biomass of prey consumed and exported from Virginia salt marsh by primary marsh predator groups. Mass and number of prey removed per square meter are listed over a sample period of 150 days (June - October 1995); gdw = grams dry weight, inds = number of prey individuals. Note that estimates for marsh fringe are based on 120 days. Table based on data from Cicchetti 1998: Ch. 4, Fig. 6.

crabs were the dominant exporter of prey biomass for all habitats – unvegetated benthic habitat adjacent to marsh edge, marsh edge facing open bay, marsh fringe (within 3 m of edge) and marsh interior (> 3 m from edge), ranging from 5 to 10 fold higher in export than transient fish (Table 17-1). Edge habitat exported the greatest biomass of prey per unit area, but marsh interior was the largest source of biomass to the open water of the bay, due to the large spatial extent of this habitat type.

From these examples, it appears that marsh-derived energy is made available to offshore fisheries in the form of fish biomass, rather than detrital forms of carbon. In response to a decade's long debate about the importance of salt marsh primary production for transient nekton, Deegan *et al*. (2000) review the evidence supporting this role for marsh-estuarine ecosystems. Growth rates of larval fish are related to water temperature, so the warmer temperatures of the shallower marsh waters should confer a growth advantage. Gulf menhaden in Louisiana support this notion, having higher growth rates in the warmer waters of marsh creeks compared to the bay (Deegan 1990).

Stable isotope studies support the trophic importance of primary production from both emergent grasses (*Spartina* spp.) and / or benthic microalgae (Hughes and Sherr 1983, Peterson and Howarth 1987, Sullivan and Moncreiff 1990, Currin *et al*. 1995, Deegan and Garritt 1997). Using stable isotope analysis, fifteen common transient nekton species at four sites from Massachussetts to Georgia, show marsh-derived organic matter as an important energy source. At the Parker River estuary in northern Massachusetts, benthic feeding fishes showed a stronger dependence on marsh primary producers than the pelagic feeders, which had isotope signatures more similar to the phytoplankton. Some nekton species are able to assimilate particulate marsh grass detrital aggregates – grass shrimp, sheepshead minnow (*Cyprinodon variegatus*), Atlantic menhaden (*Brevoortius tyranus*), and two mullet species (*Mugil* spp.). In the Deleware Bay, isotope analysis reveals the size-specific feeding movements and down bay export of marsh-derived organic matter by juvenile weakfish (*Cynosion regalis*). Salt-marsh macrophyte production accounted for a substantial proportion of the organic matter exported from the Bay in the form of weakfish (*Cynoscion regalis*) biomass (Litvin and Weinstein 2004).

Invertebrate prey provide the dominant link between the primary producers, microbially modified marsh grass detritus, and the nekton. Through their feeding, they convert marsh-derived production into biomass available to nekton. Taxa important in the diets of small fish include polychaetes and oligochaetes, snails, insects and their larvae, and numerous crustaceans – harpactacoid and calanoid copepods, ostracods, mysids, tanaids, amphipods, small crabs, and palaemonetid shrimp. Diet analysis of four common transient fish species in Deleware Bay (bay anchovy – *Anchoa mitchilli*, weakfish – *Cynosion regalis*, spot – *Leiostomus xanthurus*, Atlantic croaker – *Micropogonius undulatus*) revealed a clear seasonal pattern of foraging (Nemerson 2001, Nemerson and Able 2004). Young fish were planktivorous in the spring, feeding on zooplankters (calanoid copepods and mysids), switching at larger body size to larger marsh-associated prey (epibenthic crustaceans, annelid worms, fish). Weakfish and spot fed on young of the year (YOY) mummichogs as they left the marsh surface for creeks in midsummer. Spot and croaker appeared to forage preferentially at sites of high prey abundance, based on the relationship between gut fullness and the densities of these two species. YOY striped bass had highest abundance in the lower salinity marsh creeks of the upper Bay, and became increasingly piscivorous with growth. Nearly half of their diet (46.2 % by weight) was fish; 52% of these prey fish were mummichogs, and 27% were Atlantic croaker.

SALT MARSH POOLS

Permanent salt marsh pools are a ubiquitous feature of the Reserve's high marsh plain (Wilson 2006, Fig. 17-5). On the Webhannet marsh, there are 5,549 pools, the great majority of which (87%) are < 46.5 m ^{2} (≈ 3.6 m in diameter). Pool surface area comprises 13.1% of the vegetated marsh area (50.7 ha), whereas low marsh is 7.4 % (28.8 ha). Despite the abundance of this marsh habitat, only a handful of studies have investigated high marsh pool ecology (Talbot *et al.* 1986, Murphy 1991, Smith and Able 1994, Able *et al.* 1996, Halpin 2000, Smith and Able 2003). These pools (Fig. 17-6) often contain high densities of grass shrimp (*Palaeomonetes pugio*) and mummichog. On higher tides, the pools are flooded and connect with the extended estuarine ecosystem. The frequency of high marsh tidal flooding varies from year to year, depending on interannual anomalies and long term cycles (Morris *et al.* 2002), but as an example, a survey of water levels and marsh elevation on the Webhannet marsh revealed that 26 % of tides flooded the marsh from 9/5/06 to 10/9/06.

A recent study at Wells NERR investigated fish production and food web structure in pools on the Webhannet and Moody marshes (MacKenzie and Dionne 2006). A large scale experiment using small mesh fencing maintained the natural biological assemblage of marsh pools under three treatment regimes: nekton restricted to pools, nekton with access to marsh surface equal to 3 times pool area, and nekton unrestricted control (see photos and Fig. 17-5). Fish from all three treatments had similar production rates, indicating that marsh pools function as net producers of fish biomass. The upper range of production rates in pools (1.15 g dw mo^{-1}) were higher than those measured in tidal creeks and channels from the one other New England study to measure mummichog production (in southern Massachusetts, Valiela *et al.* 1977), although the size class of fish used in that study (> 60 mm) may not be directly comparable to the production for the large size class of fish in our study (> 40 mm), since smaller individuals have higher production. When all size classes of fish are included, pool fish production on the Webhannet marsh was 1 g dw mo^{-1}, 1.16 g dw mo^{-1} for the Moody marsh, as compared to 2.38 g dw mo^{-1} from a New Jersey marsh (Teo and Able 2003). Marsh production in the Reserve's salt marsh pools appears to fit the expected gradient of reduced production with increasing latitude, and appear to be as productive as salt marsh creeks. Given that there is nearly twice as much pool habitat as low marsh habitat in the Webhannet marsh, and the Moody marsh is likely similar, marsh pools are an important and productive habitat in these two northern New England salt marshes.

Enclosure on Webhannet marsh excluding marsh pool fish from high marsh habitat. Photo Michele Dionne.

Enclosure on Webhannet marsh allowing fish to access the marsh surrounding a marsh pool. Photo Michele Dionne.

Food web analysis using stable isotopes from the same study revealed that in year 1 food sources from salt marsh pools (i.e., benthic microalgae, epiphytic algae, phytoplankton) contributed up to 75% of adult fish diets in unrestricted control treatments and up to 60% in pool-plus-marsh treatments. The marsh surface (*Spartina patens*) contributed the remaining 25% of fish diets in control treatments and 40% in pool-plus-marsh treatments. In

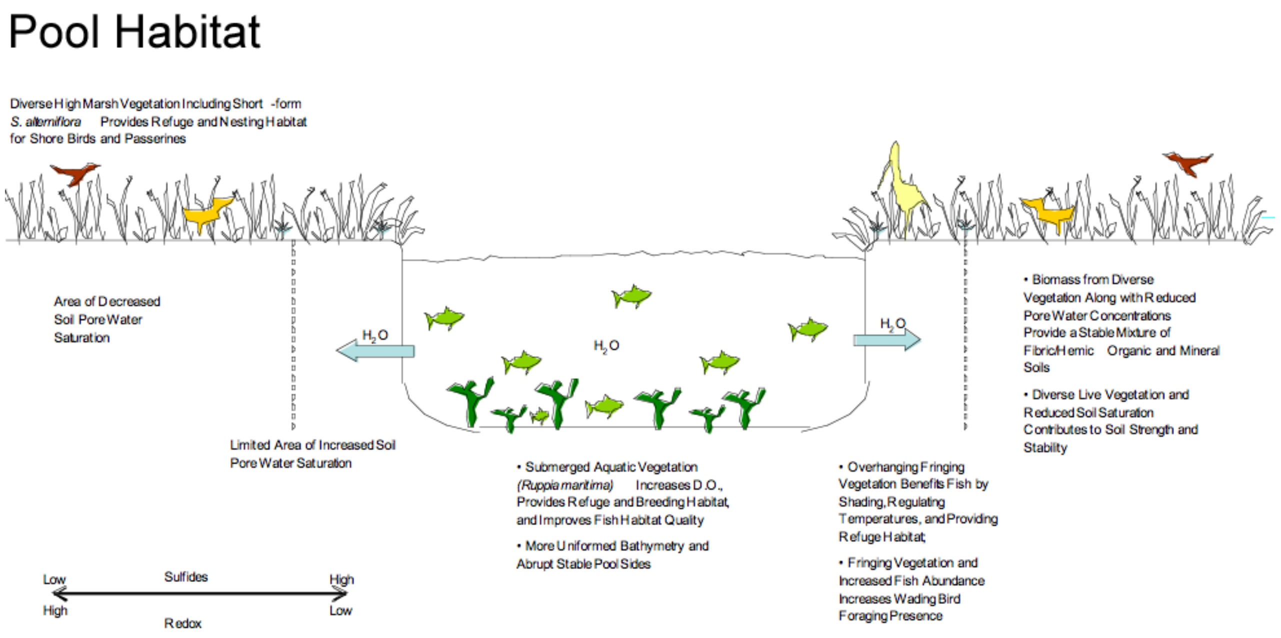


Figure 17-5: Typical characteristics of pool habitat on the salt marsh. Source Robert Vincent.

year 2, the value of the marsh surface as a food source increased by nearly a factor of 2 (40%) in unrestricted control treatments and by nearly a factor of 3 (65%) in pool-plus-marsh treatments. In contrast to results from adult fish, food sources in marsh pools contributed 70-90% of large YOY fish (20-40 mm) diets and 95-100% of small YOY fish (< 20 mm) diets.

HUMAN INFLUENCES

Nitrogen (N) is the critical element that limits plant growth in marsh-estuarine ecosystems, and therefore is an important driver of salt marsh primary production. When the supply of nitrogen is augmented by human actions, plant and algal production is stimulated, leading to an increase in plant biomass. In the open waters of estuaries, dead plant biomass can collect in benthic habitats and drive down dissolved oxygen (DO) levels as it decays via microbial respiration. This pattern of change is termed cultural eutrophication, or nutrient enrichment. In the coastal United States, estuarine eutrophication is a recognized problem, including many Northeastern estuaries (Bricker *et al.* 1999, Bricker *et al.* 2006). Increases in primary production and reductions of dissolved oxygen can affect the chemical, habitat and trophic (i.e.,food web) structure of marsh-estuarine ecosystems, including effects on nekton (Simenstad *et al.* 2000, Deegan 2002 and references therein). Deegan (2002) synthesizes the potential processes by which eutrophication can influence salt marsh productivity, and identifies many alternative hypotheses in need of testing.

Salt marsh grasses can respond to N addition through increased production, plant height, and leaf N content. Cordgrass stem density was sometimes reduced in N fertilization experiments (Valiela *et al.* 1978, Vince *et al.* 1981, Boyer and Zedler 1998). The location of plant zonal boundaries can change in response to added N, with the net effect of reducing the area of salt hay meadow (Bertness 2004; see also Ch. 16). In a study of fringing marshes in Rhode Island, increasing N loading (N delivered to the estuary from the upland via water inputs) had a negative effect on salt marsh hay density and extent, and a positive effect on the extent of smooth cordgrass. Reduced stem density will reduce the anti-predator function of low marsh for juvenile fishes, and possibly make it easier for predators to access the high marsh on flooding tides.

Marsh grass biomass and stem density also play an important role in salt marsh peat formation and maintenance of elevation with respect to sea level rise. Under normal conditions, plant organic matter and sediment (trapped by the marsh grasses) accumulate on the marsh surface adequately to keep pace with increasing sea level. Deegan (2002) describes a hypothetical scenario whereby the increased microbial peat decomposition (shown to occur in response to nutrient additions in small plot experiments) leads to marsh platform subsidence. This loss of marsh elevation may not occur in the low marsh if increased plant biomass from N enrichment leads to more rapid substrate accretion, compensating any trend towards subsidence (sinking) from increased microbial activity. In the high marsh the marsh platform may subside because sediment supply will be reduced, being trapped more efficiently by the increased biomass of smooth cordgrass in the low marsh. Once the marsh loses elevation, increased inundation time will depress plant production, leading to further subsidence (see photo). Ultimately, this process can lead to expansion of open water relative to vegetated marsh, and a fragmentation of salt marsh structure. This would greatly reduce the production and protection functions of the marsh for nekton.

Low dissolved oxygen (hypoxia) is a common occurrence in the lower water column of eutrophied estuaries (Diaz 2000). During brief hypoxic episodes, benthic invertebrates are distributed closer to the sediment-water interface, and can suffer increased predation from fish, but only if the fish can tolerate the conditions (Nestlerode and Diaz 1998). Anoxic events (dissolved oxygen < 2 mg L^{-1}) can lead to the loss of an entire fish year class. Low DO has been shown to substantially reduce growth in some fish species (e.g. winter flounder). Young fish may behave differently in response to low DO, with increased swimming (to seek higher DO water), and reduced predator avoidance behavior (Breitburg 2002). Bottom waters with < 2 mg L^{-1} DO have very low fish abundances, while total abundance and species richness

Example of marsh subsidence, in this case likely due to peat oxidation after extensive ditching reduced the original water table. After subsidence, water levels are higher than the marsh surface. Source Maine Office of GIS, 2003.

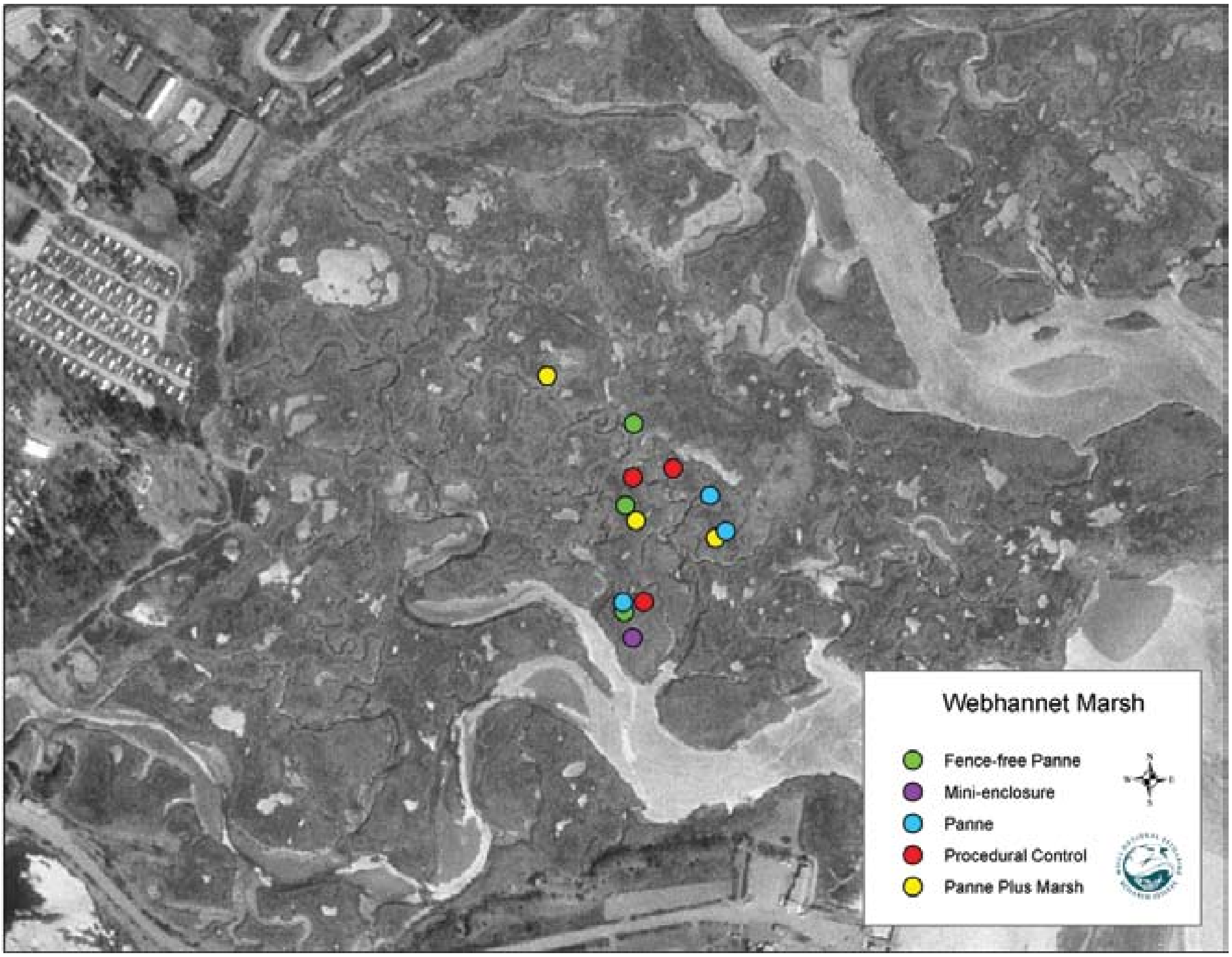


Figure 17-6: Sample design for marsh pool feeding study on Webhannet Marsh. Source Richard MacKenzie.

tend to decline gradually with declines in DO above this threshold.

Food webs can be altered by cultural eutrophication as well. Increased N leads to increased benthic algal biomass, boosting populations of algae-grazing fauna. Algal biomass is more readily assimilated than marsh plant detritus, shifting the food web to a greater dependency on algae. This may then lead to decreased DO and a shift in the benthic infaunal community to just a few, more abundant, larger bodied species. Increased prey size may well reduce the feeding ability of the small fishes that are the first step in the trophic relay process.

REFERENCES

Able, K.W., D.A. Witting, R.S. McBride, R.A. Rountree, and K.J. Smith. 1996. Fishes of polyhaline estuarine shores in Great Bay—Little Egg Harbor, New Jersey: a case study of seasonal and habitat influences. *In* Estuarine shores: evolution, environments and human alterations *Edited by* Nordstrom, K.F. and C.T. Roman. Wiley New York, NY. 335–353 pp.

Bell, S.S., and B.C. Coull. 1978. Field evidence that shrimp predation regulates meiofauna. . Oecologica 35: 141-148.

Bertness, M.D. 2004. Salt marshes under siege. American Scientist 92: 54-61.

Boyer, K. and J. Zedler. 1998. Effects of nitrogen additions on the vertical structure of a constructed cordgrass marsh. Ecological Applications 8: 692-705.

Bozeman, E.L., Jr. and J.M. Dean, 1980. The abundance of estuarine larval and juvenile fish in a South Carolina intertidal creek. Estuaries 3: 89-97.

Breitburg, D. 2002. Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries. Estuaries 25(4b): 767-781.

Bricker, S. B., C. G. Clement, D. E. Pirhalla, S. P. Orlando, and D. R. G. Farrow. 1999. National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries. NOAA/NOS/Special Projects Office and National Centers for Coastal Ocean Science, Silver Spring, MD. 71 pp.

Bricker, S.D., D. Lipton, A. Mason, M. Dionne, D. Keeley, C. Krahforst, J. Latimer and J. Pennock. 2006. Improving methods and indicators for evaluating coastal water eutrophication: a pilot study in the Gulf of Maine. NOAA Technical Memorandum NOS NCCOS 20. National Ocean Service, Silver Spring, MD. 82 pp.

Cicchetti, G. and R.J. Diaz, 2000. Types of salt marsh edge and export of trophic energy from marshes to deeper habitats. *In* Concepts and controversies in tidal marsh ecology. *Edited by* M.P. Weinstein and D.A. Kreeger. Kluwer, Boston, MA. 515-451 pp.

Conover, D.O. and S. Murawski, 1982. Offshore winter migration of the Atlantic silverside, *Menidia menidia.* Fishery Bulletin 80: 145-149.

Couch, C.A. 1989. Carbon and nitrogen stable isotopes of meiobenthos and their food resources. Estuarine, Shelf, and Coastal Science 28: 433-441.

Currin, B.M., J.P. Reed, and J.M. Miller. 1984. Growth, production, food consumption, and mortality of juvenile spot and croaker: a comparison of tidal and non-tidal nursery areas. Estuaries 7: 451-459.

Currin, C.A., S.Y. Newell, and H.W. Paerl. 1995. The role of benthic macroalgae and standing dead *Spartina alterniflora* in salt marsh food webs: implications based on multiple stable isotope analysis. Marine Ecology Progress Series 121: 99-116.

Currin, C.A., S.C. Wainwright, K.W. Able, M.P. Weinstein and C.M. Fuller. 2003. Determination of food web support and trophic position of the mummichog (*Fundulus heteroclitus*), in New Jersey smooth cordgrass (*Spartina alterniflora*), common reed (*Phragmites australis*), and restored salt marshes. Estuaries 26(2B): 495-510.

Deegan, L.A. 1990. Effects of estuarine environmental conditions on population dynamics of young-of-the-year gulf menhaden. Marine Ecology Progress Series 68: 195-205.

Deegan, L.A. and B.A. Thompson. 1985. The ecology of fish communities in the Mississippi River deltaic plain. *In* Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration. *Edited by* Yanez-Arancibia, A. UNAM-ICML Publishers, Mexico, DF

Deegan, L.A., J.E. Hughes and R.A. Rountree. 2000. Salt marsh ecosystem support of marine transient species. *In* Concepts and controversies in tidal marsh ecology. *Edited by* Weinstein, M.P. and D.A. Kreeger. Kluwer, Boston, MA. 333-365 pp.

Deegan, L.A. and R.H. Garritt. 1997. Evidence for spatial variability in estuarine food webs. Marine Ecology Progress Series 147: 31-47.

Deegan, L. A. 2002. Lessons learned: the effects of nutrient enrichment on the support of nekton by seagrass and salt marsh ecosystems. Estuaries 25(4B): 727-742.

Diaz, R. J. 2000. Overview of hypoxia around the world. Journal of Environmental Quality 30: 275-281.

Guidi, L.D. 1984. The effect of food composition on ingestion, development, and survival of a harpacticoid copepod, *Tisbe cucumariae.* Journal of Experimental Marine Biology and Ecology 84: 101-110.

Halpin, P.M. 2000. Habitat use by an intertidal salt-marsh fish: trade-offs between predation and growth. Marine Ecology Progress Series 198: 203-214.

Hughes, E.H. and E.B. Sherr. 1983. Subtidal food webs in a Georgia estuary: ^{13}C analysis. Journal of Experimental Marine Biology and Ecology 67: 227242.

Kneib, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series 106: 227-238.

Kneib, R.T. 1997a. The role of tidal marshes in the ecology of estuarine nekton. Oceanography and Marine Biology 35(1): 63-220.

Kneib, R.T. 1997b. Early life stages of resident nekton in intertidal marshes. Estuaries: 20: 214-230.

Kneib, R.T. 2000. Salt marsh ecoscapes and production transfers by estuarine nekton in the southeastern United States. *In* Concepts and controversies in tidal marsh ecology. *Edited by* M.P. Weinstein and D.A. Kreeger. Kluwer, Boston, MA. pp. 267-291.

Kneib, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series 106: 227-238.

Kwak, T.J. and J.B. Zedler. 1997. Food web analysis of southern California coastal wetlands using multiple stable isotopes. Oecologica 110: 262-277.

Litvin, S.Y. and M.P. Weinstein. 2003. Life history strategies of estuarine nekton: the role of marsh macrophytes, benthic microalgae, and phytoplankton in the trophic spectrum. Estuaries 26(B): 552-562.

Litvin, S.Y. and M.P. Weinstein. 2004. Multivariate analysis of stable-isotope ratios to infer movements and utilization of estuarine organic matter by juvenile weakfish (*Cynoscion regalis*). Canadian Journal of Fisheries and Aquatic Sciences 61: 1851-1861.

MacKenzie, R.A. and M. Dionne. 2006. Ecological processes, energy pathways, and the impact of human activities on Maine marsh-estuarine secondary production: a salt marsh panne model. Report to Maine Sea Grant Wells National Estuarine Research Reserve, Wells, ME. 55 pp.

Middaugh, D.P. 1981. Reproductive ecology and spawning periodicity of the Atlantic silverside. Copeia 1981: 766-776.

Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve and D.R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. Ecology 83(10): 2869-2877.

Murphy, S.C. 1991. The ecology of estuarine fishes in southern Maine high salt marshes: access corridors and movement patterns. Masters thesis. University of Massachusetts, Amherst, MA. 109 pp.

Nelson, A.L. and B.C. Coull. 1989. Selection of meiobenthic prey by juvenile spot (Pisces): an experimental study. Marine Ecology Progress Series 53: 51-57.

Nestlerode, J. A. and R. J. Diaz. 1998. Effects of periodic environmental hypoxia on predation of a tethered polychaete, Glycera americana: implications for trophic dynamics. Marine Ecology Progress Series 172:185-195.

Nemerson, D.M. 2001. Trophic dynamics and habitat ecology of the dominant fish of Delaware Bay (USA) marsh creeks. Dissertation, Rutgers University, New Brunswick, NJ. 244 pp.

Nemerson, D.M. and K.W. Able. 2004. Spatial patterns in diet and distribution of juveniles of four fish species in Delaware Bay marsh creeks: factors influencing fish abundance. Marine Ecology Progress Series 276: 249-262.

Newell, S.Y. and D. Porter. 2000. Microbial secondary production from salt marsh grass shoots, and its known and potential fates. *In* Concepts and controversies in tidal marsh ecology. *Edited by* Weinstein, M.P. and D.A. Kreeger. Kluwer, Boston, MA. 159-185 pp.

Newell, S.Y. and F. Barlocher. 1993. Removal of fungal and total organic matter from decaying cordgrass leaves by shredder snails. Journal of Experimental Marine Biology and Ecology 171: 39-49.

Patterson, A.W. and A.K. Whitfield. 1997. A stable carbon isotope study of the food-web in a freshwater-deprived South African estuary, with particular emphasis on the ichthyofauna. Estuarine, Shelf, and Coastal Science 45: 705-715.

Peterson, B.J., and R.W. Howarth. 1987. Sulfur, carbon and nitrogen isotopes used to trace organic matter flow in the salt-marsh estuaries of Sapelo Island, Georgia. Limnology and Oceanography 32: 1195-1213.

Rountree, R.A. 1992. Fish and macroinvertebrate community structure and habitat use patterns in salt marsh creeks of southern New Jersey, with a discussion of marsh carbon export. Dissertation, Rutgers, the State University of New Jersey, New Brunswick, NJ.

Rountree, R.A. and K.W. Able. 1992. Foraging habits, growth and temporal patterns of salt marsh creek habitat use by juvenile summer flounder in New Jersey. Transactions of the American Fisheries Society 121: 765-776.

Simenstad, C. A., S. B. Brandt, A. Chalmers, R. Dame, L. A. Deegan,R. Hodson, and E. D. Houde. 2000. Habitat-biotic interactions. In Estuaries: a synthetic approach to research and practice. Edited by J. E. Hobbie. Island Press, Washington, D.C. 427-455.

Smith, K.J. and K.W. Able, 1994. Salt-marsh tide pools as winter refuges for the mummichog, *Fundulus heteroclitus*, in New Jersey. Estuaries 17(1B): 226-234.

Smith, K.J. and K.W. Able. 2003. Dissolved oxygen dynamics in salt marsh pools and its potential impacts on fish assemblages. Marine Ecology Progress Series 258: 228-232.

Sullivan, M.J. and C.A. Moncreiff, 1990. Edaphic algae are an important component of salt marsh food-webs: evidence from multiple stable isotope analyses. Marine Ecology Progress Series 62: 149-159.

Talbot, C.W., K.W. Able and J.K. Shisler. 1986. Fish species composition in New Jersey salt marshes: effects of marsh alterations for mosquito control. Transactions of the American Fisheries Society 115: 269-274.

Teo, S.L.H., and K.W. Able. 2003. Growth and production of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh. Estuaries 26: 51-63.

Valiela, I., J. M. Teal, and W. G. Deuser. 1978. The nature of growth forms in the salt marsh grass, Spartina alterniflora. The American Naturalist 112: 461-470.

Vince, S., I. Valiela, and J. Teal. 1981. An experimental study of the structure of the herbivorous insect communities in a salt marsh. Ecology 62:1662-1678.

Weinstein, M.P., S.L. Weiss and M.F. Walters, 1980. Multiple determinants of community structure in shallow marsh habitats, Cape Fear River Estuary, North Carolina, USA. Marine Biology 58: 227-243.

Wiegert, R.G. and L.R. Pomeroy, 1981. The salt marsh ecosystem: a synthesis. *In* The ecology of a salt marsh. *Edited by* Pomeroy, L. R. , and R. G. Wigert. Springer-Verlag, New York NY.

Wilson, K.R. 2006. Ecogeomorphology of salt pools of the Webhannet estuary, Wells, Maine, USA. Masters thesis, University of Maine, Orono, ME. 98 pp.

Zijlstra, J.J. 1988. Fish migration between coastal and offshore areas. *In* Coastal-offshore ecosystem interactions. *Edited by* Jansson, B.O. Springer-Verlag. 257-272 pp.

V. RESEARCH & MONITORING

Research Program

Monitoring Program

CHAPTER 18

Research Program

MICHELE DIONNE

RESEARCH ACTIVITIES, PRIORITIES AND NEEDS[1]

Program Overview

The Wells NERR Research Program studies and monitors change in Gulf of Maine estuaries, coastal habitats, and adjacent coastal watersheds, and produces science-based information needed to protect, sustain, or restore them. In a typical year, the program directs or assists with more than 20 studies involving dozens of scientists, students, and staff from the Reserve, academic and research institutions, resource management agencies, and environmental and conservation groups. A privately endowed fund supports a Wells NERR post-doctoral fellowship, allowing program staff to benefit from the expertise of 2- to 3-year-term visiting scientists.

Wells NERR scientists participate in research, monitoring, planning, management, and outreach activities, locally, regionally and nationally. The program supports field research along Maine's southwest coast from the Kennebec River to the Piscataqua River, including nearshore and offshore waters of the Bigelow Bight. Within this region, effort is focused on the coastal compartments from Kittery to Cape Elizabeth, which are characterized by numerous marsh-dominated estuaries and barrier beaches.

The Wells NERR Research Program will continue to focus its efforts on investigations of coastal food webs, the habitats that support them, and the human-mediated and natural disturbances that alter them. In addi-

Research interns sample fish and invertebrate populations in the Reserve's salt marsh pool habitat. Photo Richard McKenzie.

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[1] Parts of this and the following section also appear in the 2007 Wells NERR Management Plan.

tion, we continue to actively promote the development and implementation of regionally coordinated ecological monitoring of coastal habitats along the gradient of least disturbed, to restored, to most disturbed. This will be accomplished through committee work, meetings, workshops, presentations, and reports. New efforts within the Research Program include the development of programmatic ties with one or more academic institutions.

The Reserve maintains professional relationships with colleagues at the University of New Hampshire, the University of New England, Brown University, Boston Universty (see photo), Antioch New England Graduate School, Dartmouth College, Bates College, the University of Maine, and the University of Southern Maine. The Research Coordinator participates on committees for graduate students from the University of New Hampshire, the University of Maine, the University of Southern Maine, Antioch New England, and Brown University. We have begun to explore formal program partnerships with one or more of these institutions. Programs to be considered include: 1) academic-year course offerings by Reserve staff, 2) undergraduate and graduate on-site field research courses, 3) expanded coastal research and training opportunities for students, post-baccalaureate students, and faculty, 4) semester-long research internships for undergraduates, 5) a Restoration Ecology Institute and Certification Program for academic credit.

A visiting graduate student from Boston Univeristy downloads data in the MCEC from the Reserve's wave-current meter. Photo Michele Dionne.

The lack of adequate shoreland buffers threaten the ecological integrity of Gulf of Maine salt marshes, including the Reserve's Webhannet River marsh. Wells NERR photo.

In a given year, Research Program staff work closely with 10-20 undergraduate and graduate interns during both the academic year and the summer field season. In general, the students work on Reserve-sponsored research projects. Many students work for credit or to meet a service requirement. Others receive stipends from project funds or through internships (funded in part by the Laudholm Trust). Program staff also work closely with citizen volunteers, particularly on watershed / estuary water quality monitoring projects. The Research Program benefits enormously from the time, energy, enthusiasm, and interest of these students and volunteers. In return, interns often use their experience at Wells NERR as a step toward environment-related employment or graduate study. The benefit to Wells NERR continues when interacting with former interns in their professional capacity as members of the regional environmental research and management community.

RESEARCH THEMES

Salt Marsh Habitats and Communities

Factors that control the dynamics and vigor of salt marsh plant communities and marsh peat formation determine the ability of a salt marsh to persist in the face of sea level rise. Through a combination of experimental manipulations and long term monitoring, we are producing data to answer questions concerning the sustainability of natural and restored salt marsh habitats in this region (see photo). These studies address land-use impacts, nutrient-plant relations, plant community responses to physical and hydrologic disturbance, and the relative contribution of short-term natural events (e.g., storms) and human activities (e.g., dredging, tidal restriction) on patterns of sediment accretion and erosion. The Reserve's marshes and beaches are among the best-studied sites nationally with regard to long-term accretion and erosion (over thousands of years). The barrier beaches that protect these marshes have also been well studied, especially with respect to alterations due to human activity and sea level rise (see photo).

The combination of jetties, seawalls, and sea level rise have resulted in severe beach erosion on the Drakes Island barrier. When originally constructed, these walls barely protruded above the surface of the beach. Wells NERR photo.

Habitat Value for Fish, Shellfish, and Birds

The Reserve combines long-term monitoring with periodic surveys and short-term experiments to identify species and measure trends and changes in populations of fish, crustaceans, clams, and birds. We have more than 10 years of data on upland birds, wading birds, and shorebirds for assessing population status. Our wading bird data are used as a gross indicator of salt marsh health. Our periodic larval, juvenile, and adult fish surveys have produced the best available data for fish utilization of salt marsh estuaries in the Gulf of Maine. We are currently focused on the development of nekon indicators of shoreland land use impacts on estuarine habitat. We have conducted surveys and field experiments to look at the survival and growth of hatchery seed, juvenile and adult softshell clams, as well as their favored habitat characteristics and predation by the invasive green crab. Our food web studies are quantifying the movement of energy and contaminants from primary producers to nekton.

Reserve staff monitor the recreationally harvested softshell clam population in the Webhannet estuary. Wells NERR photo.

Salt Marsh Degradation and Restortation

Since 1991, the Wells NERR has been studying the impact of tidal restrictions on salt marsh functions and values, and the response of salt marshes to tidal restoration. Salt marsh ecosystems in the Gulf of Maine sustained themselves in the face of sea-level rise and other natural disturbances for nearly 5,000 years. Since colonial times large areas of salt marsh have been lost through diking, draining, and filling. Today, the remaining marshland is fairly well protected from outright destruction, but during the past 100 years, and especially since the 1950's, salt marshes have been divided into fragments by roads, causeways (see photo), culverts, and tide gates. Tidal flow to most of these fragments is severely restricted, leading to chronic habitat degradation and greatly reduced access for fish and other marine species. Currenlty, we are studying how adjacent land use change is altering

Common reed (Phragmites australis) is a serious threat to hydrologically altered salt marshes, and the focus of many salt marsh restoration efforts. Photo Michele Dionne.

the amount and quality of freshwater flow into Gulf of Maine marshes (see photo). Under the umbrella of the Global Programme of Action Coalition for the Gulf of Maine, and the Gulf of Maine Council on the Marine Environment, the Reserve evaluates monitoring results from marsh restoration projects throughout the Gulf to assess their performance and to identify data gaps and future monitoring needs (Dionne and Neckles 2000, Neckles *et al.* 2002, Konisky *et al.* 2006, Taylor 2007).

Much of the landscape adjacent to salt marsh in the southern Gulf of Maine has lost all or part of its vegetated buffer. This allows soils to bake and harden, and to shed water that often carries nutrients and herbicides directly onto the marsh. Photo Michele Dionne.

The research themes summarized here contribute to five of eight grand challenges in environmental science identified by the National Research Council and highlighted by Omenn in his 2006 presidential address to the American Association for the Advancement of Science (Omenn 2006). They are: biogeochemical cycles and their perturbations; biological diversity and ecosystem functioning; climate variability - local and regional; hydrologic forecasting - floods, droughts, contamination; and land use and land cover dynamics.

RESEARCH PRIORITIES

As the outcome of the Reserve's recently completed strategic planning process, the Wells NERR Research Program research priorities were summarized as follows:

Investigate coastal food webs and habitats, their underlying physical and biological processes, and their response to natural changes and human activities.

To pursue this research mandate we identified the following strategies:

- ◊ Investigate the ecology of estuarine and coastal habitats and food webs along the Gulf of Maine.
- ◊ Evaluate the effectiveness of coastal habitat restoration along the Gulf of Maine.
- ◊ Support investigations regarding salt marsh fish production.
- ◊ Support investigations regarding the quantity and quality of estuarine and watershed resources.
- ◊ Promote the investigation of linkages between estuaries and open water in the Gulf of Maine.
- ◊ Promote a landscape ecology approach to the conservation of coastal lands and watersheds.
- ◊ Collaborate with other agencies to determine coastal research needs relevant to resource management.
- ◊ Participate in system-wide scientific work groups addressing how wetlands, estuaries, and nearshore ecosystems respond to land use within coastal watersheds.

The Reserve's sediment profile imager (SPI) on its way to sampling stations in the Gulf of Maine. Photo Richard MacKenzie.

- ◊ Provide scientific support for education, outreach, and training efforts to manage and protect freshwater and tidal shorelands in watersheds.

RESEARCH NEEDS

In 2004, Wells NERR participated as a member of the Regional Association for Research in the Gulf of Maine (RARGOM) in a RARGOM-sponsored workshop on coastal habitat change and land use. This workshop was the ten-year follow up to RARGOM's first workshop, also on Gulf of Maine habitats (the Reserve's research coordinator was one of the organizers of this inaugural workshop). In the 2004 workshop, the following research needs were agreed to:

1. Develop a land use analytical tool for the Gulf of Maine watershed to complement the vision of the Gulf of Maine Integrated Ocean Observing System.
2. Develop a tool kit of indicators to identify and track land use change and ecosystem response.
3. Assess environmental response to different patterns of land use, specifically, concentrated versus dispersed development.

The Wells NERR Research Program, with its commitment to research topics of relevance to coastal habitat integrity, protection, and restoration, agrees that these research initiatives should be given the highest priority.

RESEARCH FACILITIES AND FACILITY NEEDS

Maine Coastal Ecology Center

The 6,000-square-foot Maine Coastal Ecology Center (MCEC), completed in 2001, is a state-of-the-art facility. The MCEC holds offices for research and stewardship staff, interns, and visiting investigators; a research laboratory (pictured); a geographic information system center; an interpretive exhibit area; a break room; and a laboratory specifically designed for teaching. The MCEC is in good condition and needs only ongoing maintenance and repair.

The original plan for the MCEC called for a 200-square-foot environmental research chamber adjoining the research laboratory. This climate-controlled room for experiments on ecological processes of natural coastal systems was left incomplete, but is an important part of the long-range facility needs of Wells NERR Research Program. This need is anticipated to be met in 2007.

The MCEC lab on a busy afternoon. Photo Richard MacKenize.

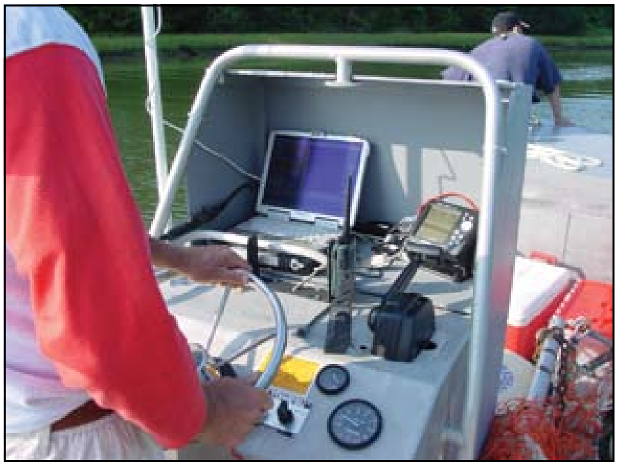
The nearly intact Little River estuary is a favorite location for field research by visiting investigators. Photo Wells NERR.

Boats and Equipment

The Research Program maintains on-hand a full suite of basic field gear needed for estuarine ecological research. The Reserve's research fleet includes two small v-hulled skiffs (12 ft), motors (4 – 10 hp) and a trailer, as well as a larger (22 ft) v-hulled skiff, motor (70 hp), and trailer (see photo of boat). Field equipment includes an array of fish sampling nets (lift, seine, fyke, dip), battery-operated top-loading scales, petite and full-sized benthic grabs, and a Leica TCRA 1205 Total Survey Station. The Research Program also possesses a Benthos Underwater Sediment Profile Imaging (SPI) system with both deep- and shallow-water frames, with cabled underwater video camera for real-time observation of habitat and equipment during use (pictured). Lab equipment includes an array of optics: 16 Zeiss Stemi-DV4 student stereomicroscopes (in the teaching lab), a Zeiss Stemi SV6, a Zeiss SV11 with Leica photo system, a Zeiss Axiostar Plus compound microscope, a Reichert Microstar IV compound microscope, and a Reichert Bio-Star inverted compound microscope. De-ionized water is supplied by a Millipore Direct-Q filtration system. A large built-in hood, a benchtop hood (teaching lab) and safety storage closets are used when working with hazardous chemicals and preservatives. A sliding door refrigerated chamber with temperature control is available for short term biological sample storage, or experiments. There are two refrigerators and two freezers for cold storage. A drying oven, muffle furnace, top-loading (Fisher A-220D) and analytical balances (Fisher XD-8KD), benchtop centrifuge, and field-ready fluorometer (Turner Design 10-AU) are also used by staff and visiting investigators. The teaching lab is outfitted with equipment needed to process basic water quality variables (dissolved oxygen, turbidity, chlorophyll a, salinity, fecal coliform), and has two deep sinks suitable for seiving field samples.

Field Sites

Wells NERR supports studies within several local estuaries and watersheds. The Research Program is currently at capacity with respect to its ability to provide on-site staff support to visiting investigators, and is approaching capacity for its relatively small field site (see photo).



The Reserve's 22-ft research vessel, the "R&D," at work collecting data to create countour maps of estuarine water quality parameters. Wells NERR photo.

The Reserve encourages visiting investigators to consider alternative salt marsh estuaries for their studies, but does not control access to these sites. Researchers using sites outside the Reserve boundary collaborate with Reserve staff but must comply with the research protocols of the host location. Wells NERR would benefit greatly from an expansion of the coastal area within which its scientists regularly conduct research.

FACILITY NEEDS

Geospatial Information

In order to effectively carry out research on the regional response of marsh-estuarine ecosystems to tidal restoration and sea leve rise, we will continue to seek funds for a Real Time Kinematic Global Positioning System (RTK-GPS), and to establish the Reserve as a Continuously Operating Reference Station (COR). High resolution 3-D geospatial measurement of habitats is essential to accurately measure patterns of tidal inundation and habitat change. For the past ten years we have relied on benchmarks established by visiting investigators. This has greatly hampered our ability to survey and map our study sites, given that we have no control over the number, location and accuracy of these benchmarks. In addition, our current total survey station instrument, (an optical device) while highly accurate, requires a line of sight to make measurements. This constraint is a serious impediment, as it often takes a number of sequential sightings to carry a benchmark to the location where it is needed. Many of our study sites have also been invaded with the common reed (*Phragmites australis*), a tall (5- to 12-ft), densely growing plant. Cutting through this stiff vegetation to make sightings is laborious and time consuming.

A real-time kinematic global positioning system (mobile base station and receiver), as well as a COR station, will greatly expand our capacity to pursue hypotheses about coastal habitat response to change agents. We will be able to quickly measure georeferenced position in both the horizontal and vertical dimensions at the resolution needed to address our hypotheses on a meaningful time scale (e.g. annual rather than decadal). The COR station will allow the use of both mobile components of the RTK GPS instrument package to collect spatial data, using the COR signal broadcast, rather than dedicating one of the two mobile units to signal broadcasting, effectively doubling the amount of data that can be collected per unit time. Both the mobile units and the COR station will be a great asset for the workof the Research Program, as for nearly all field work conducted by project collaborators, graduate students, visiting investigators, natural resource professionals, and members of the conservation community in Southern Maine. We will make this equipment readily available to the larger community of conservation partners, watershed managers, environmental consultants and coastal habitat monitoring groups, with staff assistance as needed. Taken together, the RTK GPS instrument package and the COR station will greatly increase the productivity and scope of our field research, and enable us to design more competitive research projects, hence increasing our external research funding levels.

Access to Field Sites

As the number and / or intensity of research projects focused on the Reserve's estuaries increases (see photo of Little River), it will be necessary to provide simple, removable, raised boardwalks for access to some field sites, to minimize disturbance to the vegetated marsh. We will work with the Reserve's Stewardhip Program to develop an appropriate design, and seek funding for materials, construction and installation. If possible, we will enlist the help of the Americorps Program to accomplish this task.

One of the many manipulative field experiments carried out at the Wells NERR. Here, soft-shell clam growth and survival are being measured in the presence and absence of their green crab predator. Photo Michele Dionne.

The Reserve's small skiffs (pictued) have v-hulls and are less useful in shallow water than vessels with flat-bottomed hulls. In order to have a stable platform able to work a wider range of the tide, we should add a small flat-bottomed skiff and short-shaft motor to our fleet. In order to deploy our Sediment Profile Imaging (SPI) camera system, a flat bottomed vessel with an A-frame boom at the stern is needed to safely accommodate the great weight of the camera frame. At present we are required to seek external funds for the use of an appropriate vessel to undertake research focused on benthic habitat quality in coastal waters.

Monitoring Priorities and Needs

Overview

Water quality is monitored continuously at several stations with automated instruments as part of the System-wide Monitoring Program, as well as bimonthly at 15 to 20 stations through the Watershed Evaluation Team (WET) volunteer monitoring program. These data 1) have allowed us to identify several bacterial "hot spots," 2) are used to identify and open areas safe for shellfishing, and 3) have uncovered a relation between tides and dissolved oxygen levels. Our water quality work has contributed to the designation of several "Priority Watersheds" in coastal southern Maine by the Maine Department of Environmental Protection, and our water quality data have recently been used as part of a NOAA Northeast regional assessment of estuarine eutrophication (Bricker *et al*. 2006). Our partnership with Maine Sea Grant and the University of New Hampshire has identified species-specific sources of bacterial contamination in our coastal watersheds (Whiting-Grant *et al.* 2004a,b).

Monitoring Priorities

As the outcome of the Reserve's recently completed strategic planning process, the Wells NERR Research Program monitoring priorities were summarized as follows:

Promote the development and implementation of regionally coordinated ecological monitoring of coastal habitats, and continue to maintain and expand the System Wide Monitoring Program (SWMP).

To pursue this monitoring mandate we identified the following strategies:

- ◊ Fully implement and expand the SWMP, including bio-monitoring and land-use change analysis.
- ◊ Collect, maintain, and analyze consistent SWMP data for weather, water quality, nutrients, vegetation, and land-use change using standardized protocols and technologies.

- ◊ Organize, review, document, and submit quality-controlled SWMP data to the Central Data Managment Office.
- ◊ Promote and increase awareness of SWMP data within the Gulf of Maine scientific community.
- ◊ Link SWMP and other monitoring efforts with the Gulf of Maine Ocean Observing System and the national Integrated Ocean Observing System.
- ◊ Contribute to local, regional, and Gulf of Maine initiatives involving restoration science and coastal habitat monitoring.

Census of Marine Life Gulf of Maine Area Program New England Seascape Change Detection

As part of our commitment to coastal environmental monitoring, the Research Program has particpated in and helped organize numerous regional workshops and conferences during its 15 year tenure, and has contributed to their proceedings and implementation. Most recently, the Research Program convened and summarized the outcome of a Coastal Working Group meeting for the Census of Marine Life Gulf of Maine Area Program (CoML-GOM). The Coastal Working Group agreed upon the following outline for future research, which the Wells NERR Research Program endorses.

Rationale: Episodic and chronic disturbances such as storms, oil spills, species invasions, non-point source pollution and climate change inevitably affect coastal ecology and biodiversity. Without a dedicated program to measure conditions and species over time, we lack the ability to predict variation and change adequate to inform effective conservation, prevention and restoration measures.

Geographic Scope: The CoML Coastal Network would track an informative suite of biological variables in coastal ecosystems in Connecticut, Rhode Island, Massachusetts, New Hampshire, Maine, linked with an existing network in Long Island Sound. The design of the network would be informed by the few existing coastal long-term biological monitoring efforts (e.g. Department of Fisheries and Oceans Canada – in southwest Bay of Fundy; Bowdoin College – at Kent Island).

Seascape Change Detection: The change-detection network would collect species-level larval settlement data to detect change relevant to Gulf of Maine coastal biodiversity. Parameters and processes of interest include: range shifts, species dispersal envelopes, larval advection and retention, physical-biological coupling, recruitment events and dynamics, cohort survival and production, and arrival and spread of invasive populations.

These phenomena are all related, at some level, to one or more of the four major research themes that emerged from the meeting discussion. Most of these parameters would shed light on the ecological consequences of oceanographic and climate forcing (Theme I - *Physical Oceanographic and Climate Forcing*), and ecological linkages between estuarine, nearshore and offshore waters (Theme IV – *Ecosystem Linkages*). Similarly, the database would allow investigators to infer regional patterns of benthic productivity, very relevant to theme III (*Biodiversity and Ecosystem Function*) and also to theme II (*Habitats and Food Webs*). These are but a few of many possible examples highlighting the value of a biological change detection program to enhance understanding of biodiversity-relevant coastal functions and processes. Over time, these data would enable quantitative modeling to predict the response of Gulf of Maine coastal ecosystems to changes in chemical, physical and biological drivers.

REFERENCES

Bricker, S.D., D. Lipton, A. Mason, M. Dionne, D. Keeley, C. Krahforst, J. Latimer, and J. Pennock. 2006. Improving methods and indicators for evaluating coastal water eutrophication: a pilot study in the Gulf of Maine. NOAA Technical Memorandum NOS NCCOS 20. National Ocean Service, Silver Spring, MD. 82 pp

Konisky, R.A., D.M. Burdick, M. Dionne and H.A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology 14(4): 516-525.

Neckles, H.A., and M. Dionne. 2000. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine, a GPAC Workshop Report to the Commission for Environmental Cooperation. Wells National Estuarine Research Reserve, Wells, ME. 21 pp.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum and E. Hutchins. 2002. A monitoring protocol to assess tidal marshes at local and regional scales. Restoration Ecology 10(3): 556-563.

Ommen, G.S. 2006. Grand challenges and great opportunities in science, technology, and public policy. Science 314: 1698-1704.

Taylor, P.H., 2007. Salt marshes in the Gulf of Maine: human impacts, habitat restoration, and long-term change analysis. Gulf of Maine Council on the Marine Environment. 45 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S.J. Jones. 2004a. Microbial source tracking in two southern Maine watersheds: executive summary for Merriland River, Branch Brook, and Little River (MBLR) watershed. Wells National Estuarine Research Reserve Wells, ME. 7 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S.J. Jones. 2004b. Microbial source tracking in two southern Maine watersheds: Merriland River, Branch Brook, and Little River (MBLR) watershed report. Wells National Estuarine Research Reserve, Wells, ME. 56 pp.

CHAPTER 19

Monitoring Programs

JEREMY MILLER

Monitoring activities at Wells NERR have a strong focus on water quality, but also include a newly established emergent vegetation monitoring effort, an odonate survey, and monitoring of piping plover, least tern, and upland bird populations. In addition, beach profiling and marine debris monitoring programs are made possible by volunteers who work alongside Wells NERR staff.

SYSTEM WIDE MONITORING PROGRAM AND NATIONAL WATER LEVEL OBSERVING NETWORK

The System Wide Monitoring Program (SWMP) was established by the National Estuarine Research Reserve system in 1995 to track short term variability and long term changes in estuarine environments within the NERR system. The program consists of three phased-in components: abiotic parameters, biological monitoring, and watershed and land use classification. Abiotic monitoring began system-wide with the deployment of water quality sondes in 1995. Since 2001, each NERR has been tasked with deploying at least four sondes, collecting in situ readings around the clock at 30 minute intervals and one meteorological station to collect weather data. Monthly nutrient and chlorophyll-a monitoring via grab samples began in 2001. Plans for the phased-in implementation of the other components are under way. Data are collected and submitted for quality control to the Centralized Data Management Office (CDMO) in Charleston, South Carolina, on a yearly cycle, (Owen *et al.* 2005).[1]

Wells NERR began environmental monitoring as part of SWMP in April 1995, when the first water quality station was installed at the head of tide in the Webhannet estuary. In May of that year, a second site was established at Wells Harbor. Both of these initial sites are still active. The Laudholm Farm Meteorological Station was deployed in 1996 to collect weather data around the clock. Two additional water quality sites were added in 2002, Mile Road (ML) beginning in March in the Webhannet River estuary and Little River Mouth (LM) in April in the Merriland / Branch / Little River Estuary. For 2004, the Mile Road (ML) site was eliminated and a new site at Skinner Mill (SM) in the Merriland / Branch / Little River Estuary was added. This logger was initially placed just above the head of tide and was moved to a new location a few hundred meters downstream at the beginning of the 2006 season.

The Wells Harbor station is deployed year-round, given its location in an ice-free inlet. The other loggers are

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[1] For more information about SWMP, see: http://cdmo.baruch.sc.edu/.

Figure 19-1: Location of System Wide Montioring Program data logger deployment sites in Wells NERR estuaries.

removed in late December and redeployed in March to avoid ice damage. Typically, deployments are two to three weeks in duration. Sondes are calibrated before each deployment, and data are downloaded upon retrieval. An additional sonde allows deployment of a freshly calibrated sonde at the same time the previous sonde is retrieved, reducing gaps in data collection. At each deployment and retrieval, a YSI Model 85™ handheld unit collects temperature, DO mg/L, DO %, and salinity. These parameters are recorded and compared to the sonde data. A detailed manual prepared by CDMO guides every step of the calibration, deployment, and data review process.

Currently, all data loggers are YSI 6600 series™ installed in vertical, vented deployment tubes attached to a dock piling or large steel stakes. They have 1/4 inch black polyethylene mesh wrapped on the outside of the protective housing of the sonde probe guard to reduce fouling (pictured) and intrusion by animals. In addition, since 2004, SWMP has used the YSI extended deployment system consisting of a brush which sweeps the sensors before each reading, greatly reducing algal growth and other fouling issues. The deployment depth for each site is such that the probe-end of the data logger is secured 0.15 m (6 in) off the bottom (Note: Wells Harbor station probes are 1m off the bottom). Water levels at the Webhannet Head of Tide and MBLR Mouth sites can be very low when low tide and low river flow occur together. It is not unusual that the sonde depth sensor is out of the water at low tide, but all remaining sensors, being approximately 17 cm lower, are very rarely at risk of exposure to the atmosphere.

Two to four week variable sampling periods were chosen for all data sondes due to limitations created by the life of the dissolved oxygen membrane, probe fouling, limited battery power, and to minimize risk of lost data in the event of a malfunction. Parameters for both water quality and meteorological monitoring (Table 18-1) have been recorded at 30 and 15 minute intervals respectively throughout the deployment period.

Nutrient and chlorophyll-a sampling at Wells NERR occurs at the above stations on a monthly cycle during the ice free season. Two grab samples of one liter each are taken approximately six inches below the surface at each station. In addition, at the Wells Harbor site, diel sampling occurs in the 24 hours leading up to the grab samples. An ISCO™ automatic sampling machine collects 12 one liter samples from about six inches off the bottom of the harbor over two full tidal cycles (or one sample every two hours, four minutes). The samples are kept on ice in the sampler until they are retrieved. Once in the lab, the samples are filtered and frozen, usually within 2 hours of collection. They are shipped frozen, next day delivery to a lab for analysis for the five nutrient parameters of interest.

Telemetry, or the delivery of data to remote users in real time or near real-time, is an important element of SWMP. Although telemetry efforts have been ongoing at Wells NERR for over six years, the NERR system recently implemented a standardized, nationwide program using the Geostationary Operational Environmental Satellites (GOES) system, a critical component of the Integrated Ocean Observing System (IOOS). The data are transmitted via satellite at 15 minute intervals, and are used by National Weather Service's Hydrometeorological

Water Parameters	Weather Parameters
pH	Temperature (°C)
Conductivity (mS/cm)	Wind speed and direction (m/s;°)
Salinity (ppt)	Relative humidity (%)
Temperature (°C)	Barometric pressure (mb)
Dissolved Oxygen (%)	Rainfall (mm)
Turbidity (NTU)	Photosynthetic Active Radiation (mM/m^2, total flux)
Nitrate (mg/L)	
Ammonia (mg/L)	
Ortho-Phosphate (mg/L)	
Chlorophyll a (µg/L)	

Table 19-1: Abiotic parameters measured by the System Wide Monitoring Program.

Automated Data System, and can be viewed online by anyone. The Wells NERR SWMP coordinator is currently the Regional Telemetry Support Technician for the Northeast SWMP telemetry system. The Reserve will continue to support telemetry and other efforts that integrate with the Gulf of Maine Ocean Observing System and IOOS. More generally, the Reserve will promote awareness of SWMP data within the Gulf of Maine scientific community.

There are two sampling sites in the Webhannet River estuary. These are located at the Head of Tide (HT) and at the Webhannet Harbor Inlet (IN). The Webhannet Head of Tide site (HT) is located 4 miles south of the Wells NERR campus, just downstream of the Webhannet Falls (freshwater) and 3 m east of U.S. Route One. Depths at this site range between 2 m during dry periods and 1.47 m on exceptionally high tides and during heavy runoff events. U.S. Route One receives heavy traffic all year, with extremely high levels during the summer tourist months. The salinity range here is 0-31 psu (practical salinity units), with a mean of 3.6 psu. By contrast, the watershed of the Webhannet is relatively undeveloped.

The Webhannet inlet site is located 1.5 miles south of the Wells Reserve, at the Wells Harbor pier. The Webhannet estuary forms an extensive wetland / salt marsh area which is surrounded by development. Wells Harbor, which was most recently dredged in 2000, has moorings for approximately 200 commercial fishing and recreational boats. The mouth of the river flows between two long jetties to the Atlantic Ocean. This site has a

Close up of a YSI 6600-series water quality monitoring sonde used in the System Wide Monitoring Program. Photo Jeremy Miller.

Fouling of a delployment tube for a data logger, exposed at a n extreme low tide. Photo James Dochtermann.

predominately sandy substrate and is characterized by strong current during incoming and outgoing tides. The maximum depth range of the Inlet site is 2.38 to 6.74m. The salinity range here is 7-35 psu, with a mean of approximately 31 ppt. The Inlet site is considered the most heavily impacted of the four sites.

The Little River Mouth site is located 0.4 miles from the Wells NERR campus. Heavy sedimentation problems forced the relocation of this site somewhat upstream of the Little River mouth in 2003. The tidal range of the Little River estuary is 2.6-3.0 meters (Mariano and FitzGerald 1989). Depth typically ranges from 0.24 to 2.39 m, with greater range seen at during spring tides and storm events. The Little River site exists in a shallow and relatively pristine system with a sandy to mud bottom and a salinity range of 0-32 psu. There are two major freshwater inputs, the Merriland and Branch Brook Rivers, which converge to form the Little River.

The Skinner Mill (SM) site was located approximately 20 meters downstream from the intersection of the Merriland River (tributary to Merriland River / Branch Brook / Little River (MBLR) estuary) and Skinner Mill Road. The site was also located approximately 8 meters downstream from a former mill site with cobbles and the low head remnants of a dam. This location is at the transition point from medium to sparse residential development upstream in the watershed to undeveloped, protected salt marsh. Depths typically range from 0.24 to 1.6 m. Substrate is rock, salinities were always less than 1 ppt. Originally, the site was thought to have some estuarine influence, although the data appeared to show otherwise. Therefore in the summer of 2006, the sonde was moved about 200-300 yards downstream to better represent a head of tide scenario. This new location sees salinities in the range of zero to 31.5 parts per thousand and depths range from 0.24 m during dry periods to as deep as 2.42 during spring tides and / or heavy runoff events. The substrate is muddy channel bottom and there is no adjacent development or impervious surfaces.

The weather station is located (43° 20.244' Latitude, 70° 33.000' Longitude) on a 32 ft telephone pole surrounded by mowed grass. The temperature and humidity probes are located on the north side of the pole at a height of 10 ft. To the northwest of the pole is the Coastal Ecology Center, a 20 ft high, 111 ft long building, at a distance of 37 ft, running northeast / southwest. Farther to the northwest (153 ft from the pole) is the library, in a 25 ft high wing of the barn. The barn itself is 223 ft from the station and runs northeast / southwest. It is 38 ft high and is the largest obstruction in the area. The rain gauge is located 9 ft southeast of the weather station pole and is situated on a post with the top of the funnel is 10 ft from the ground.

Weather data is collected every 15 seconds, with averages are taken and data reported as 15 minute intervals. The data is directly downloaded from a Campbell Scientific CR1000™ datalogger and the data is then run through a QA/QC process and formatted for delivery to the CDMO.

In the summer of 2005, Wells NERR was integrated into the National Water Level Observing Network with the installation of a continuous water level station at the Wells Harbor (IN) SWMP site. The NWLON is a network of 175 long-term, continuously operating water-level stations throughout the USA, including its island possessions and territories and the Great Lakes[2]. The NWLON has expanded over time in response to increasing national and local needs. NWLON stations are the foundation for reference stations for NOAA's tide prediction products, and serve as controls in determining tidal datums for all short-term water-level stations. Technological advancements in sensors, data collection and data communications have enabled routine real-time automated and event-driven data acquisition using the GOES satellite. NWLON data-collection platforms are now capable of measuring other oceanographic parameters in addition to water levels, including meteorological parameters. Because of these advancements, the application of NWLON data and products has broadened.

Watershed Evaluation Team (W.E.T.)

The Wells NERR Watershed Evaluation Team (W.E.T.) is a volunteer-based water quality monitoring program. It was established in the fall of 1991 when citizens from several communities in York County, Maine came to-

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[2] To view NWLON data, see http://tidesandcurrents.noaa.gov/nwlon.html.

Figure 19-2: W. E. T. monitoring sites. Map Wells NERR.

Figure 19-2: Long-term vegetation monitoring transects on the Webhannet marsh. The colored dots represent fixed plots for plant community composition monitoring. Map Wells NERR.

gether under the direction of Reserve staff and began characterizing and monitoring the aquatic environment of the Little and Webhannet River estuaries.

The long-term goal of the program is to better understand the relationships between estuarine ecological conditions and human land use in surrounding watersheds. Because of the complexity of estuarine systems, consistent, accurate and comparable data must be collected over many years. Therefore, the success of the water quality monitoring program depends greatly on the sustained efforts of a well-trained group of concerned citizen volunteers and middle and high school students, who learn about laboratory skills, water quality, and area ecosystems while helping to collect data.

Information on sources of pollution in the estuaries is provided to local officials and resource managers to facilitate their efforts in protecting our estuarine environment and human health. Sample collection takes place at 16-20 sites every other week from March through December (Fig. 19-2). Water temperature, air temperature, tide stage, and weather observations are recorded at each site when samples are collected. Samples are then analyzed in the Wells NERR teaching lab for dissolved oxygen, turbidity, pH, salinity, chlorophyll, and fecal coliform bacteria.

EMERGENT VEGETATION MONITORING

Long-term monitoring of salt marsh emergent vegetation can document changes in the Reserve's tidal wetlands associated with future changes in land use, sea level, and tidal restoration, as well as changes associated with ongoing impacts initiated in the past, such as road crossings. Documenting change on the scale of entire marsh systems will provide much needed evidence to support pro-active policy and permitting decisions by the coastal management community.

Although this project was completed with one-time funding, it provides baseline data to support future work within the framework of the NERR Systemwide Monitoring Program Phase 2 (biological monitoring). The project included both landscape level (Tier I), and transect level (Tier II) monitoring. The Tier II sampling was designed to measure vegetation change associated with runoff from residential and commercial development.

An increase in nutrient-enriched freshwater runoff from parking lots, roofs, and other impervious surfaces, coupled with a thinning or removal of the riparian border, may faciliate the expansion of the common reed, *Phragmites australis*, from the upland edge onto the high marsh plain. Studies in Rhode Island salt marshes have shown a strong correlation between upland development and the invasion of *Phragmites* (Bertness *et al.* 2002, 2004). Increased freshwater runoff and sediment deposition from construction make conditions more inviting for *Phragmites* as well (Chambers, et. al. 2003).

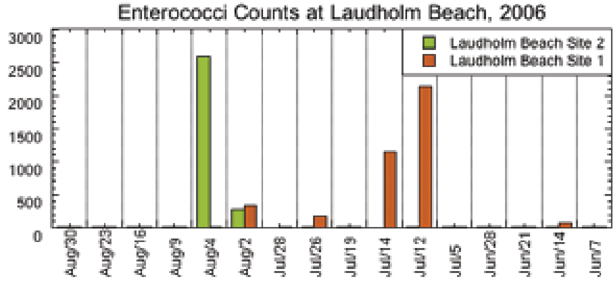

Figure 19-3: Enterococci bacterial concentrations at Laudholm Beach 2006. Source Maine Healthy Beaches. Figure Hannah Wilhelm.

For Tier 1, a composite map of the major plant communities (smooth cordgrass, salt marsh hay, *Phragmites*) of the Webhannet River estuary using aerial photographs was completed. Reserve staff walked the zonal boundaries of the Webhannet marsh with handheld GPS to create a georeferenced database to overlay on georeferenced aerial photos (1 ft ground sample resolution, 1:400 scale).

For Tier II, the composition of marsh plant communites and marsh elevation along four sets of paired transects (reference vs. impact) was measured in the Webhannet Marsh (Fig. 18-2). Transects were selected using spatial analysis of aerial photos. Reference transects were perpendicular to well buffered uplands, and impact transects were perpendicular to uplands that had been cleared by development. The transects extended from the upland edge of the marsh to the vegetated edge of the first large channel. Each transect has five permanent 1 m^2 plots marked by PVC pipe. The first plot is in the *Phragmites* / cattail / black rush zone, the next three are in the salt marsh hay high marsh zone, and the last is in the smooth cordgrass low marsh zone. Percent cover of all plant species (using 50 point intercept in a 0.25 m^2 quadrat) was recorded for each plot. Groundwater depth and salinity was measured on several dates using permanent wells (60 cm x 3.8 cm PVC pipe) located at each plot. Transect and plot elevations, accurate to 1 cm or less, were recorded using a Leica TCRA 1205 total survey station. Analysis of treatment effect (control vs. impact) on the plant community, and the influence of groundwater depth, salinity, and tidal inundation are in progress.

MAINE HEALTHY BEACHES PROGRAM

In 2002, the following the national Beaches Environmental Assessment, Closure and Health (BEACH) Act of 2000, the Maine Healthy Beaches Program began monitoring bathing beaches for enterococci, a bacterial indicator. Presence of enterococci means that dangerous species such as *Cryptosporidium*, *Giardia*, *Shigella*, and *E. coli* may be present as well. Wells NERR volunteers and staff collect water samples at coastal swim beaches to be tested for bacterial counts (Fig. 18-3). Data is used by local and state agencies as well as by the U.S. Environmental Protection Agency. Decisions about beach closings are made using a risk assessment incorporating specific environmental conditions that have been found to produce high bacterial counts. (Maine Healthy Beaches Program 2006).

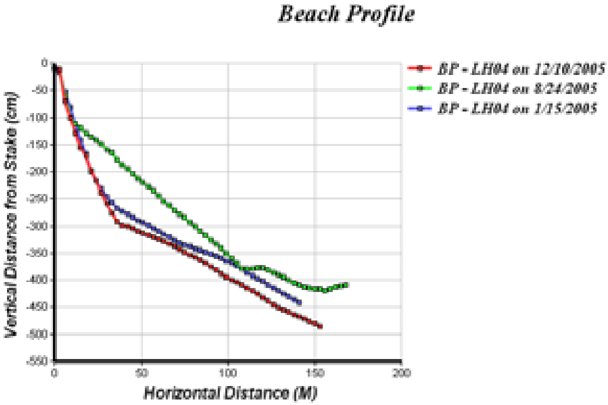

Figure 19-4: Beach profiles for the Reserve's Laudholm Beach on three dates in 2005. The series represents the elevation of the sand from the dunes to low water and provides monthly data on erosion. Source Southern Maine Beach Profiling Program.

SOUTHERN MAINE BEACH PROFILING PROGRAM

The sandy beaches in southern Maine are one of the state's primary tourist attractions, as well as important habitats for wildlife. Beaches are dynamic features; however, they respond to a variety of forcing mechanisms. Because of growing population and increase in development along the coast in the past several decades, it is necessary to study and comprehend changes that are occurring in these systems. Beach profiling is a simple surveying technique used to measure the contour of a beach (pictured). Long-term beach profiling data is the first step to un-

Ocean-based Items		**Land-based Items**		**General**	
Gloves	45	Syringes	16	Plastic bags w/ seam < 1m	307
Plastic sheets ≥ 1 meter	12	Condoms	47	Plastic bags w/ seam ≥ 1m	51
Light bulbs/tubes	6	Metal beverage cans	536	Straps (open)	179
Oil/gas containers	3	Motor oil containers	5	Straps (closed)	23
Pipe-thread protectors	3	Balloons	376	Plastic bottles (beverage)	157
Nets ≥ 5 meshes	101	Six-pack rings	2	Plastic bottles (food)	41
Traps/pots	131	Straws	123	Plastic bottles (bleach/cleaner)	15
Fishing Line	134	Tampons	12	Other plastic bottles	169
Light sticks	5	Cotton swabs	2		
Rope ≥ 1 meter	654				
Salt bags	48				
Fish baskets	2				
Cruiseline logo items	25				
Floats/buoys	150				
Total	1319	Total	1119	Total	942

Table 19-2: Total numbers of trash items found on the Reserve's Laudholm Beach through the Marine Debris Monitoring Program 1996-2006. Data Ocean Conservancy.

derstanding how fast and why our beaches are changing - data critical to making informed decisions about beach management issues (Fig. 18-4). The Wells NERR acts as a host site for the University of Maine Cooperative Extension and Maine Sea Grant contracts staff time to help run and maintain this volunteer-based program.

SHELLFISH GROWING AREA CLASSIFICATION PROGRAM

The Shellfish Growing Area Classification Program is a water quality monitoring program run by the Maine Deparment of Marine Resources. Reserve staff assist with data collection, which happens at least six times per year at several locations in the Webhanet and Little River Estuaries. Samples are analyzed for fecal coliform levels. National Shellfish Sanitation Program (NSSP) standards are used for evaluation. Also included in the project are shoreline surveys, visual searches for sewage outflow or other potential conaminents. Sanitary survey documents are published, describing areas where harvesting is advised or prohibited (Maine DMR 2006).

MARINE DEBRIS MONITORING PROGRAM

The National Marine Debris Monitoring Program, coordinated by The Ocean Conservancy, has a study station at the Reserve's Laudholm Beach. The program is a study of the effectiveness of the International Treaty on Marine Pollution (MARPOL), which was ratified by the U.S. in 1998. The treaty prohibits the disposal of all plastic garbage at sea. For other types of waste common on board ships, the treaty established disposal limits.

Volunteers measure the elevation profile of Wells Beach for Maine Sea Grant's Beach Profiling Program. Their efforts provide information about beach erosion or accretion. Photo Cayce Dalton.

Every month, a group of staff and volunteers head to Laudholm Beach with Ocean Conservancy trash bags and data sheets to record the weather, the wind direction, and all trash discovered. Data is sent to the Ocean Conservancy where it is compiled in reports describing the source and content of the debris being collected (Table 18-2;The Ocean Conservancy 2006).

MAINE DAMSELFLY AND DRAGONFLY SURVEY

The Maine Department of Inland Fisheries and Wildlife is conducting a 5-year, volunteer-based survey of insects in the order Odonata (damselflies and dragonflies, pictured). 158 species of odonates have been recorded in Maine, nearly 36% of all North American odonate species. In 1998, additional support has since been provided by the US Fish and Wildlife Service. The Reserve has been participating in the MDDS program since 2001 with two sites surveyed several times during the odonates flight season (approx. April-October). The Reserve is host to two species of note: the seaside dragonlet (*Erythrodiplax berenice)* and the citrine forktail (*Ischnura hastata*), both relatively rare in New England. The seaside dragonlet is most often found along coastal plains and brackish tidal estuaries. It is one of only a few odonates that can utilize brackish water for egg laying. The citrine forktail was recorded at the Wells NERR in 2001. Previously there had only been four records of this damselfly in Maine, the last being recorded in 1938 (MDDS 2006).

Wells NERR staff participate in the Maine Damselfly and Dragonfly Survey. Photo Susan Bickford.

PIPING PLOVER AND LEAST TERN MONITORING

Maine Audubon coordinates a Piping Plover and Least Tern Recovery Project at the Wells National Estuarine Research Reserve and other locations along the coast of Maine. The piping plover monitoring program consists of searching for active plover nest sites (pictured), and when found, enclosing the nesting area for protection (see photo). Beaches are closed off from the public and predators are actively removed either by crow traps or a local wildlife nuisance control person (for removal of mammals).

In 1995, only 40 pairs of piping plover, *Charadrius melodus*, were nesting in Maine. Maine Audubon collaborated with the Maine Department of Inland Fisheries and Wildlife, landowners and town officials in Wells

Volunteers conduct a beach clean-up on Laudholm Beach. Data on the type and quantity of debris are recorded and forwarded to the National Debris Monitoring Program. Photo Andrea Leonard.

to manage nesting piping plovers on the town's beaches. A voluntary agreement assured the piping plovers were protected, without having to designate essential habitat. After nearly two years of negotiation, these factions, and the U.S. Fish and Wildlife Service, came to an agreement representing their local beach communities. In 2000, Wells town voters also passed the agreement at a town meeting.

As a result of the beach management agreement, there is an active piping plover protection program in Wells. In 2002, there were 13 pairs of plovers nesting in the town, constituting 20% of the Maine's plover population. The town of Wells hired a coordinator to recruit volunteers to monitor the birds and lead educational programs. Town beach management activities are better recorded and techniques used for beach cleaning have been improved for chick safety. A peak of 66 nesting pairs in the State was reached in 2002. Subsequent years have showed a decline in nesting pairs due to spring storms that eroded habitat and caused pairs to re-nest, delaying hatchings until peak human and predator densities along the coast.

The least tern, *Sterna antillarum*, is also monitored at Wells and Kennebunk beaches. In 2005, 60 pairs of least terns settled on the mouth of the Little River, known as Crescent Surf Beach in Kennebunk. A closed-circuit solar electric net fence was installed around most of the colony by Rachel Carson National Wildlife Refuge staff in June. The new technique, used at the site the previous year, protected the nesting birds from mammalian predators in search of chicks and eggs. By the end of the first month, predators encroached upon nests in the unprotected area causing the terns to re-nest within the protected area boundaries. The electric fence proved a success by significantly reducing crow and mammal predation and numbers of chicks were up from the previous years.

MONITORING AVIAN PRODUCTIVITY AND SURVIVORSHIP (MAPS)

A weekly breeding season mist-net survey of Wells NERR bird populations began in 1988 and was incorporated into the MAPS program, based out of Point Reyes, California, in 1990. It is the longest-running monitoring program at the Wells NERR. See Ch. 12 for details.

Putting up a fence to prevent beachgoers and predators from intruding on plover habitat. Photo Rachel Carson National Wildife Refuge.

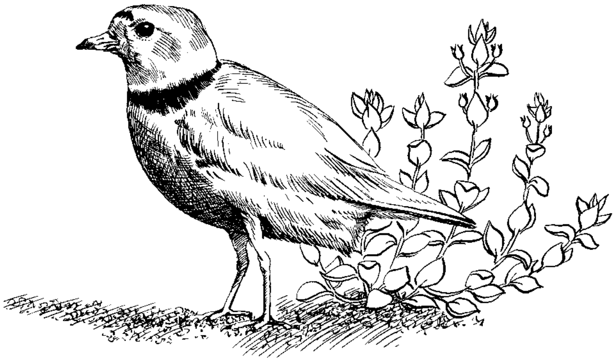

Fig. 19-5: A piping plover. Drawing Robert Shetterly.

REFERENCES

Bertness, M.D., P. Ewanchuk and B.R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. Proc Nat Acad of Sci 99(3): 1395-1398.

Bertness, M.D., B. R. Silliman, and R. Jefferies. 2004. Salt marshes under siege: Agricultural practices, land development, and overharvesting of the seas explain complex ecological cascades that threaten our shorelines. Am Scientist 92: 54-61.

Chambers, R.M., D.T. Osgood, D.J. Bart and F. Montalto. 2003. Phragmites australis invasion and expansion in tidal wetlands: interactions among salinity, sulfide and hydrology. Estuaries 26(2B): 398-406.

Owen, B., S. White. 2005. National Estuarine Research Reserve System 10th Anniversary Report on the System-wide Monitoring Program (SWMP) Data Applications: 1995–2005. NOAA Estuarine Reserves Division, Silver Spring MD. http://www.nerrs.noaa.gov/programs/SWMPReport.pdf

The Ocean Conservancy. Marine Debris Monitoring Program. Available from http://www.oceanconservancy.org/site/PageServer?pagename=mdm_debris [Accessed 18 December 2006]

Maine Department of Marine Resources (DMR). Maine Shellfish Growing Area Classification Program. Available from http://www.maine.gov/dmr/rm/public_health/shellfishgrowingarea.htm\ [Accessed 18 December 2006]

Maine Dragonfly and Damselfly Survey. Available from http://mdds.umf.maine.edu/index.html. [Accessed 18 December 2006]

Maine Healthy Beaches Program. Available at http://www.mainehealthybeaches.org/index.html [Accessed 18 December 2006]

Maine Audubon Society. Maine's endangered shorebirds: sharing the beach with endangered species. Available from http://www.maineaudubon.org/conserve/atrisk/pplt.shtml [Accessed 19 December 2006]

Mariano, C.G. and D.M. FitzGerald. 1989. Sediment transport patterns and hydraulics at Wells inlet, Maine. Boston University, Boston, MA. 143 pp.

Bibliography

These reports and publications involve work at Wells National Estuarine Research Reserve by visiting investigators and staff, as well as work in the surrounding region by staff and students.

Adamowicz, S.C. and C.T. Roman. 2002. Initial ecosystem response of salt marshes to ditch plugging and pool creation: experiments at Rachel Carson National Wildlife Refuge (Maine). University of Rhode Island, United States Geological Survey, Narragansett, RI. 102 pp.

Anderson, R.B. and L.A. Franecki. 1989. Avian observations of an intertidal sandbar and surrounding boundaries, Wells Harbor, Wells, Maine. Timson, Schepps & Peters, Inc., Hallowell, ME. 73 pp.

Argow, B.A. 2007. Winter processes of New England salt marshes. Dissertation, Boston University, Boston, MA. 379 pp.

Argow, B. and D.M. FitzGerald. 2006. Winter processes on northern salt marshes: evaluating the impact of in-situ peat compaction due to ice loading, Wells, ME. Estuarine, Coastal and Shelf Science. 69(3-4): 360-369.

Arundel Kennebunk Kennebunkport Watershed Association Steering Committee. 2001. Kennebunk River watershed nonpoint source pollution survey. Maine State Department of Environmental Protection. 16 pp.

Attar Engineering Inc. 1996. Hydrologic investigations of Drakes Island culvert and marsh. Attar Engineering, Inc., Eliot, Maine. 63 pp.

Ayvazian, S.G., L. Deegan and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. Estuaries 15(3): 368-383.

Baldwin, R.F. 2005. Pool-breeding amphibian habitat use and conservation in southern Maine's urbanizing landscapes. Dissertation, University of Maine, Orono, ME. 147 pp.

Belknap, D.F., D.C. Smith and W.R. Gehrels. 1997. Environmental changes in the Wells National Estuarine Research Reserve and Pemaquid Beach salt marshes, Maine, during the past 300 years: implications for restoration of New England-type salt marshes. University of Maine, Orono, ME. 24 pp.

Belknap, D.F., J.T. Kelley and A.M. Gontz. 2002. Evolution of the glaciated shelf and coastline of the northern Gulf of Maine, USA. Journal of Coastal Research 36: 37-55.

Belknap, D.F., R.C. Shipp, R. Stuckenrath, J.T. Kelley and H.W. Borns, Jr. 1989. Holocene sea-level change in coastal Maine. *In* Neotectonics of Maine. *Edited by* Anderson, W.A. and H.W. Borns, Jr. Maine Geological Society Bulletin No. 40. pp. 85-106.

Bertness, M.D. and S.C. Pennings. 2000. Spatial variation in process and pattern in salt marsh plant communities in eastern North America. *In* Concepts and controversies in tidal marsh ecology. *Edited by* Weinstein, M.P. and D.A. Kreeger. Kluwer Academic Publishers, Boston, MA. pp. 39-57.

Bertness, M.D. and P.J. Ewanchuk. 2002. Latitudinal and climate-driven variation in the strength and nature of biological interactions in New England salt marshes. Oecologia 132: 392-401.

Black, K., D. FitzGerald and M. Rits. 2003. Models for sediment transport at Wells inlet, Maine. Unpublished report. Boston University Geology Department, Boston, MA. 8 pp.

Blecharczyk, J. 2001. Assessment of a coastal wetland: the effects of fragmentation by roadways in Old Orchard Beach, Maine. Masters thesis, Antioch New England Graduate School, Keene, NH. 55 pp.

Bonebakker, E.R., P. Shelley and K Spectre. 2000. Return the tides resource book, Conservation Law Foundation, Boston MA. 43 pp.

Bottin, R.R., Jr. 1978. Design for harbor entrance improvements, Wells Harbor, Maine. U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory, Vicksburg, MI. 89 pp.

Boumans, R.M.J., D.M. Burdick and M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10: 543-555.

Bowron, T.M., J. Graham and M. Butler. 1999. Community and social considerations in salt marsh restoration work in Nova Scotia. Ecology Action Center, Halifax, Nova Scotia. 16 pp.

Bricker, S.D., D. Lipton, A. Mason, M. Dionne, D. Keeley, C. Krahforst, J. Latimer and J. Pennock. 2006. Improving methods and indicators for evaluating coastal water eutrophication: a pilot study in the Gulf of Maine. NOAA Technical Memorandum NOS NCCOS 20. National Ocean Service, Silver Spring, MD. 82 pp.

Bright, C.S. 1996. Webhannet River sanitary survey: methods and results. Wells National Estuarine Research Reserve, Wells, ME.

Bryan, R.R., M. Dionne, R.A. Cook, J. Jones and A. Goodspeed. 1997. Maine citizens guide to evaluating, restoring, and managing tidal marshes. Maine Audubon Society, Falmouth, ME. 142 pp.

Burdick, D.M. 1994. Population characteristics of the salt marsh communities on and around the Portsmouth naval shipyard: potential ecological effects from shipyard activities. Jackson Estuarine Laboratory, Durham, NH. 75 pp.

Burdick, D.M. and M. Dionne. 1994. Comparison of salt marsh restoration and creation techniques in promoting native vegetation and functional values. New Hampshire Coastal Program, Concord, NH. 65 pp.

Burdick, D.M., M. Boumans, M. Dionne and F.T. Short. 1999. Impacts to salt marshes from tidal restrictions and ecological responses to tidal restoration. National Oceanic and Atmospheric Administration, Estuarine Reserves Division.

Burdick, D.M., M. Dionne, R.M. Boumans and F.T. Short. 1997. Ecological responses to tidal restoration in two New England salt marshes. Wetlands Ecology and Management 4(2): 129-144.

Caffrey, J.M. 2004. Factors controlling net ecosystem metabolims in U. S. estuaries. Estuaries 27(1): 90-101.

Cameron, C., T.M. Bowron, J. Hall, M. Butler and J. Graham. 2000. Getting dirty: the why and how of salt marsh restoration. Proceedings of the Salt Marsh Restoration Workshop, Wolfville, Nova Scotia. Marine Issues Committee Special Publication. Ecology Action Center, Halifax, Nova Scotia. 24 pp.

Canfield, S.K.E. 2000. Chemical analysis of anthropogenic heavy-metal contamination and its relation to land use in the Webhannet River marsh, Wells, ME. Undergraduate honors thesis, Bates College, Lewiston, ME. 59 pp.

Cartwright, M.A. 1997. Dietary habits of benthic-feeding fishes in a southern Maine salt marsh: evaluation of prey availability and feeding selectivity. Dissertation, University of Maine, Orono, ME. 151 pp.

Cervone, E. 2003. An engineering, economic and political approach to beach erosion mitigation and harbor development: a review of the beach communities of Camp Ellis, Maine, Wells, Maine, and Cape May, New Jersey. Masters thesis, University of Maine, Orono, ME. 291pp.

Chmura, G.L., P. Chase and J. Bercovitch. 1997. Climatic controls of the middle marsh zone in the Bay of Fundy. Estuaries 20(4): 689-699.

Claesson, S. 2000. A tidal archaeological resources survey in Wells, Maine. Report to the Maine Historic Preservation Commission. New England shipwreck survey initiative (NESSI), Cape Neddick, ME. 63 pp.

Coastal Services Center, National Oceanic and Atmospheric Administration. 2005. Wells National Estuarine Research Reserve community characterization. 43 pp.

Crain, C. Pattern and process in wetland vegetation across estuarine salinity gradients. Dissertation, Brown University, Providence, RI. 116 pp.

Crain, C. Shifting nutrient limitation and eutrophication impacts in marsh vegetation across estuarine salinity gradients. Estuaries and Coasts. In press.

Crain, C.M. and M.D. Bertness. 2005. Community impacts of a tussock sedge: is ecosystem engineering important in benign habitats? Ecology 86(10): 2695-2704.

Crain, C.M. and M.D. Bertness. 2006. Ecosystem engineering across environmental gradients: implication for conservation and management. BioScience 56(3): 211-217.

Crain, C.M., B.R. Silliman, S.L. Bertness and M.D. Bertness. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. Ecology 85(9): 2539-2549.

Crain, C.M., B.R. Silliman, S.L. Bertness and M.D. Bertness. 2004. Mechanisms of the spatial segregation of plants across estuarine salinity gradients. Ecology 85: 2539-2549.

Crain, C.M., K. Bromberg and M. Dionne. Impacts of altered tidal hydrology in coastal marshes of New England. *In* Anthropogenic modification of North American salt marshes. *Edited by* Silliman, B.R., M.D. Bertness and D. Strong. In press.

Dalton, C. and F. Dillon. 2004. Population assessment of *Mya Arenaria* (the soft-shelled clam) distribution in the Webhannet Estuary, Wells, Maine. Wells National Estuarine Research Reserve, Wells, ME. 9 pp.

Dalton, C., F. Dillon, S.D. Bricker and M. Dionne. 2006. Synthesis of SWMP Data for ASSETS Eutrophication Assessment of the North Atlantic Region NERR Systems. Final report to CICEET (grant NA04NOS4190109). 92 pp.

D'Amore, D.W. 1983. Hydrogeology and geomorphology of the Great Sanford Outwash Plain, York County, Maine with particular emphasis on the Branch Brook watershed. Boston University, Boston, MA.

Davis, R.A. and D.M. FitzGerald. 2004. Beaches and coasts. Blackwell Science, Oxford, England. 419pp.

Deegan, L.A., J.T. Finn, S.C. Murphy and S.G. Ayvazian. 1991. Are critical habitats determined by life history strategies or habitat availability? National Oceanic and Atmospheric Administration, Washington, DC. 141 pp.

Diaz, R.J., R. Rowe, P. Wilbur, K. Schaefer, M. Dionne, R.A. McKenzie. 2005. Benthic habitat mapping project: Webhannet and York River estuaries, Wells National Estuarine Research Reserve, Maine. Report to National Oceanic and Atmospheric Administration Coastal Services Center, Charleston, SC. 68 pp.

Dionne, M. 1993. Fish habitat value of salt marsh creation and reference sites for the New Hampshire Port Authority mitigation plan. Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH. 32 pp.

Dionne, M. 1994. Coastal habitat alteration. *In* Gulf of Maine Habitat: Workshop Proceedings, RARGOM Report number 94-2. *Edited by* Stevenson, D. and E. Braasch. pp. 113-120.

Dionne, M. 1998. Animals and secondary productivity. *In* Research in New England marsh-estuarine ecosystems: directions and priorities into the next millennium. *Edited by* Orson, R.A., R.S. Warren, W. Niering and A.P. Van Patten. Connecticut Sea Grant, Groton, CT. pp. 19-24.

Dionne, M. 1999. Fish utilization of salt marsh habitat in the Gulf of Maine. Gulf of Maine News. Spring pp. 1-7.

Dionne, M. 2000. Coastal habitat function from a fisheye perspective: what can we learn from secondary consumers? *In* Using biology to signal ecological health. Final report of a regional conference, Massachusetts Bay National Estuary Program, Boston, MA. pp. 39-40.

Dionne, M. 2000. Ecosystem indicator: fish. *In* Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. *Edited by* Neckles, H.A. and M. Dionne. Wells National Estuarine Research Reserve, Wells, ME. pp. 15-17.

Dionne, M. 2001. Pilot deployment and evaluation of the YSI 6600 vented level probe for use in the National Estuarine Research Reserve systemwide monitoring program Cooperative Institute for Coastal and Estuarine Environmental Technology. Durham, NH. 27 pp.

Dionne, M. 2002. An ecological characterization of the Gulf of Maine: estuarine, intertidal and nearshore habitats. Briefing document: inshore ecosystem framework: Atlantic Northeast Coastal Monitoring Summit. University of New Hampshire, Durham, NH. 9 pp.

Dionne, M., D. Burdick, R. Cook, R. Buchsbaum and S. Fuller. 1998. Scoping paper 5: physical alterations to water and salt marshes. Commission for Environmental Cooperation. Montreal, Canada. 57 pp.

Dionne, M., E.R. Bonebakker and K. Whiting-Grant. 2003. Maine's salt marshes: their functions, values, and restoration. Maine Sea Grant, Orono, ME. 17 pp.

Dionne, M., F.T. Short and D.M. Burdick. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.

Dionne, M., J. Dochtermann and A. Leonard. 2006. Fish communities and habitats of the York River watershed. Wells National Estuarine Research Reserve. Wells, ME. 63 pp.

Dionne, M., J. Emerson and S. Smith. 2002. Managing non-point source inputs in priority coastal watersheds: looking at shoreland land use in the Webhannet and Ogunquit watersheds. Final report to Maine Coastal Program. Wells National Estuarine Research Reserve, Wells, ME. 47 pp.

Dionne, M., M. Haas and A. Leonard. 2006. Developing an index of tidal wetland health in the Gulf of Maine using fish as indicators. Report to USEPA Office of Ecosystem Protection Small Grantees Program, Boston, MA. 25 pp.

Droszcz, M. 1996. Evaluation of the tidal salt marshes of the Webhannet River Watershed, Wells, Maine: using the New Hampshire method for evaluating tidal salt marshes.

Eberhardt, A.L. 2004. Fish versus human corridors: the impacts of road culverts on nekton community composition and movement in New England salt marshes. Masters thesis, University of New Hampshire. Durham, NH. 134 pp.

Edgerly, J. 2006. Trophic role of the invasive crab *Carcinus maenas* in a Southern Maine marsh described by stable isotopes and gut contents. Undergraduate senior thesis, Bates College, Lewiston, ME. 50 pp.

Elias, S.P., C. Lubelczyk, P.W. Rand, E.H. Lacombe, M.S. Holman and R.P. Smith. 2006. Deer browse resistant exotic-invasive understory: an indicator of elevated human risk of exposure to *Iodes scapularis* (Acari: Ixodidae) in Southern Coastal Maine woodlands. Journal of Medical Entomology 43(6): 1142-1152.

Ewanchuk, P.J.and M.D. Bertness. 2003. Recovery of a northern New England salt marsh plant community from winter icing. Oecologia 136: 616-626.

Ewanchuk, P.J. 2003. The ecology of northern New England salt marsh plant communities. Dissertation, Brown University, Providence, RI.

Ewanchuk, P.J. and M.D. Bertness. 2004. Structure and organization of a northern New England salt marsh plant community. Journal of Ecology 92: 72-85.

Ewanchuk, P.J. and M.D. Bertness. 2004. The role of waterlogging in maintaining forb pannes in northern New England salt marshes. Ecology 85(6): 1568-1574.

Federal Emergency Management Agency. 1983. Flood insurance study: town of Wells, Maine, York County. Federal Emergency Management Agency, Washington, DC.

FitzGerald, D. and S. van Heteren. 1999. Classification of paraglacial barrier systems: coastal New England, U.S.A. Sedimentology 46: 1083-1108.

FitzGerald, D.M. and C.G. Mariano. 1989. Tidal hydraulics, morphological changes and sedimentation trends at Little River inlet, Maine. Boston University, Boston, MA. 84 pp.

FitzGerald, D.M., J.M. Lincoln, L.K. Fink and D.W. Caldwell. 1990. Morphodynamics of tidal inlet systems in Maine. *In* Studies in Maine Geology. *Edited by* R. Marvinney, Maine Geological Survey. pp. 67-96.

FitzGerald, D.M., L.K. Fink and J.M. Lincoln. 1984. A flood-dominated mesotidal inlet. Geo-Marine Letters 3(1): 17-22.

FitzGerald, D.M., P.S. Rosen and S. van Heteren. 1994. New England Barriers. *In* Geology of Holocene Barrier Island Systems. *Edited by* R.A. Davis, Springer-Verlag, Berlin, Germany. pp. 305-394.

FitzGerald, D.M., T.M. Montello and C. Griffeth. 1991. Stratigraphic study of the Wells and Drakes Island-Laudholm Beach barriers and foraminiferal environmental characterization of the Wells marsh. Boston University, Boston, MA. 41 pp.

Fogel, B.N., C.M. Crain and M.D. Bertness. 2004. Community level engineering effects of *Triglochin maritima* (seaside arrowgrass) in a salt marsh in northern New England, USA. Journal of Ecology 92: 589-597.

Gehrels, W.R. 1994a. Holocene sea-level changes in the northern Gulf of Maine: regional trends and local fluctuations determined from foraminiferal analyses and paleotidal modeling. Dissertation, University of Maine, Orono, ME. 287 pp.

Gehrels, W.R. 1994b. Determining relative sea-level change from salt-marsh foraminifera and plant zones on the coast of Maine, U.S.A. Journal of Coastal Research 10: 990-1009.

Gehrels, W.R. 2004. Sea-level changes during the last millennium. *In* Encyclopaedia of coastal science. *Edited by* Schwartz, M.L. Kluwer Academic. Dordrecht, Netherlands. pp. 830-833.

Gehrels, W.R. and D.F. Belknap. 1994. Foraminifera (protozoans) as geologic indicators of changing environments in Wells salt marshes. Wells National Estuarine Research Reserve, Wells, ME. 22 pp.

Gehrels, W.R. and O. Van de Plassche. 1999. The use of *Jadammina macrescens* (Brady) and *Balticammina pseudomacrescens* (Broennimann, Lutze and Whittaker) (Protozoa: Foraminiferida) as sea-level indicators. Palaeogeography, Palaeoclimatology, Palaeoecology 149: 89-101.

Gehrels, W.R., D.F. Belknap, B.R. Pearce and B. Gong. 1995. Modeling the contribution of M2 tidal amplification to the Holocene rise of mean high water in the Gulf of Maine and the Bay of Fundy. Marine Geology 124: 71-85.

Gehrels, W.R., D.F. Belknap and J.T. Kelley. 1996. Integrated high-precision analyses of Holocene relative sea-level changes: lessons from the coast of Maine. Geological Society of America Bulletin 108: 1073-1088.

Gehrels, W.R., D.F. Belknap, S. Black and R.M. Newnham. 2002. Rapid sea-level rise in the Gulf of Maine, USA, since AD 1800. The Holocene 12: 383-389.

Gehrels, W.R., G.A. Milne, J.R. Kirby, R.T. Patterson and D.F. Belknap. 2004. Late Holocene sea-level changes and isostatic crustal movements in Atlantic Canada. Quaternary International 120: 79-89.

Gehrels, W.R., D. Hendon and D.J. Charman. 2006. Distribution of testate amoebae in salt marshes along the North American East Coast. Journal of Foraminiferal Research 36: 201-214.

Gerber, R.G. 1987. Branch Brook aquifer study. Report to Kennebunk, Kennebunkport & Wells Water District. 27 pp.

Goode, R.E. 1989. An assessment of the biological status of an intertidal sandbar in the harbor of the town of Wells, Maine. Timpson, Schepps & Peters, Hallowell, ME. 8 pp.

Grizzle, R.E. and H. Abeels. 2003. Analysis of sediment profile imaging (SPI) Imagery from the Gulf of Maine. Unpublished report. Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH. 8 pp.

Hawks, W.E. 1992. Do behavioral or life history characteristics of the white-footed mouse predict deer tick-load? Masters thesis, University of New Hampshire. Durham, NH. 46 pp.

Hayes, P.S. 2005. An estimate of the economic value of southern Maine tidal wetlands to the Maine commercial groundfish industry. Masters thesis, Antioch New England Graduate School, Keene, NH. 137 pp.

Hill, H.W., J.T. Kelley, D.F. Belknap and S.M. Dickson. 2004. The effects of storms and storm-generated currents on sand beaches in Southern Maine, USA. Marine Geology 210: 149-168.

Hoffman, C. 1995. Tidal hydrology and vegetation dynamics in the Thirty Acre Marsh, Wells, Maine. Wells National Estuarine Research Reserve, Wells, ME. 9 pp.

Hoffman, C. 1997. Wetland response to partial restoration of tidal flow: A report on salinity, water table and vegetation abundance data collected in the Drake's Island Marsh, Wells, Maine. Wells National Estuarine Research Reserve, Wells, ME. 4 pp.

Holden, W.F. 1997. Fresh water, suspended sediment and nutrient influx to the Little River and Webhannet River estuaries, Wells, Maine. Dissertation, Boston University, Boston, MA. 279 pp.

Holman, M.S. 2003. Report on the diversity and distribution of mosquito species (Diptera: Culicidae) trapped in 2002 in York, Cumberland and Knox Counties, Maine. Maine Department of Conservation. Augusta, ME. 22 pp.

Holman, M.S., D.A. Caporale, J. Goldberg, E.H. Lacombe, C. Lubelczyk, P.W. Rand and R.P. Smith. 2004. *Anaplasma phagocytophilum*, *Babesia microti* and *Borrelia burgdorferi* in *Ixodes scapularis*, southern coastal Maine. Emerging Infectious Diseases 10(4): 744-746.

Holman, M.S., R.F. Darsie, Jr. and K.A. Foss. 2006. A checklist of the mosquitoes of Maine with new state records. Journal of the American Mosquito Control Association 22(2): 327-329.

Hussey, A.M. 1970. Observations on the origin and development of the Wells Beach area, Maine. Maine Geological Survey Bulletin 23: 58-68

Iken, H. 1994. Distribution, abundance and feeding ecology of American sand lance *Ammodytes americanus* larvae in the Webhannet River estuary and Wells Bay. Masters thesis, Antioch New England Graduate School, Keene, NH. 41 pp.

Jacobson, H.A. 1988. Historical development of the saltmarsh at Wells, Maine. Earth Surface Processes and Landforms 13: 475-486.

Jacobson, H.A., G.L. Jacobson, Jr. and J.T. Kelley. 1987. Distribution and abundance of tidal marshes along the coast of Maine. Estuaries 10(2): 126-131.

Jacobson, J. 1989. An inventory of distribution and variation in salt marshes from different settings along the Maine Coast. University of Maine, Orono, ME. 15 pp.

Jennings, D.T. 2001. Spiders (Araneae) of Wells National Estuarine Research Reserve, Wells, York County, Maine. Wells National Estuarine Research Reserve, Wells, ME.

Jury, S.H., J.D. Field, S.L. Stone, D.M. Nelson and M.E. Monaco. 1994. Distribution and abundance of fishes and invertebrates in North Atlantic estuaries. ELMR Rep. No. 13. NOAA / NOS Strategic Environmental Assessments Division, Silver Spring, MD. 221 pp.

Kelley, J.T., H. Almquist-Jacobson, G.L. Jacobson, Jr., R. Gehrels and Z. Schneider. 1992. The geologic and vegetative development of tidal marshes at Wells, Maine. U.S.A. Research Report. Wells National Estuarine Research Reserve, Wells, ME. 75 pp.

Kelley, J.T., R.C. Shipp and D.F. Belknap. 1987. Geomorphology and sedimentary framework of the inner continental shelf of southwestern Maine. Maine Geological Survey Department of Conservation, Augusta, ME, Orono, ME. 86 pp.

Kelley, J.T., R.C. Shipp and D.F. Belknap. 1989. Geomorphology and late quaternary evolutions of the Saco Bay region, Maine coast. *In* Studies in Maine Geology. *Edited by* Tucker, R.D. and R.G. Marvinney. Maine Geological Survey. pp. 47-66.

Kelley, J.T., D.F. Belknap and D.M. FitzGerald. 1990. Sea-level change, coastal processes and shoreline development in northern New England. Maine Geological Survey, Augusta, ME, 9 pp.

Kelley, J.T., W.R. Gehrels and D.F. Belknap. 1995. Late holocene relative sea-level rise and the geological development of tidal marshes at Wells, Maine, U.S.A. Journal of Coastal Research 11(1): 136-153.

Kelley, J.T., S.M. Dickson, D.F. Belknap and R. Stuckenrath. 1992. Sea-level change and the introduction of late Quaternary sediment to the southern Maine inner continental shelf. *In* Quaternary Coasts of the United States, Soc. Econ. Paleo. and Mineralogists, Special Paper 48. *Edited by* Wehmiller, J. and C. Fletcher. pp. 23-34.

Kelly, J.R. 1996. Dissolved oxygen levels in Maine estuaries and embayments. Maine Department of Environmental Protection and Wells National Estuarine Research Reserve, Wells, ME. 74 pp.

Kelly, J.R. 1997. Final report on dissolved oxygen in Maine estuaries and embayments: 1996 results and analyses. Maine Department of Environmental Protection and Wells National Estuarine Research Reserve. Wells, ME. 72 pp.

Konisky, R.A. 2003. Spatial modeling and visualization of habitat response to hydrologic restoration in New England salt marshes. Dissertation, University of New Hampshire, Durham, NH. 305 pp.

Konisky, R.A. and D.M. Burdick. 2001. Analysis and modeling of the tidal hydrology of Wheeler Refuge (York, Maine). Jackson Estuarine Laboratory, University of New Hampshire.

Konisky, R.A. and D. Burdick. 2003. Analysis of tidal and storm hydrology at Drakes Island Marsh (Wells, Maine) and scenarios for improvement. Report to the Wells National Estuarine Research Reserve, Wells, ME. 17 pp.

Konisky, R.A. and D. Burdick. 2004. Effects of stressors on invasive and halophytic plants of New England salt marshes: a framework for predicting response to tidal restoration. Wetlands 24(2): 434-447.

Konisky, R.A., D.M. Burdick, F.T. Short and R.M. Boumans. 2003. Spatial modeling and visualization of habitat response to hydrologic alteration in New England salt marshes. Cooperative Institute for Coastal and Estuarine Environmental Technology, Durham, NH. 124 pp.

Konisky, R.A., D.M. Burdick, M. Dionne and H.A. Neckles. 2005. A regional assessment of saltmarsh restoration and monitoring in the Gulf of Maine. Wells National Estuarine Research Reserve, Wells, ME. 32 pp.

Konisky, R.A., D.M. Burdick, M. Dionne and H.A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology 14(4): 516-525.

Kuo, C. 1997. Hydraulic conductivity determination in the Merriland River, Branch Book and Webhannet River Watersheds, Maine. Boston University, Boston, MA.

Kuo, C. 1998. Quantitative assessment of hydrogeology in the Merriland River, Branch Brook and Webhannet River Watersheds, Wells, Maine. Dissertation, Brown University, Providence, RI. 223 pp.

Lacombe, E.H., P.W. Rand and R.P. Smith. 1993. Disparity of *Borrelia burgdorferi* infection rates of adult *Ixodes dammini* on deer and vegetation. Journal of Infectious Diseases 167: 1236-1238.

Lee, K.T., P. Jivoff and R.E. Bishop. 2005. A low cost, reliable method for quantifying coloration in *Carcinus maenas* (Linnaeus, 1758) (Decopoda, Brachyura). Crustaceana 78(5): 579-590.

Leonard, Andrea. 2002. Merriland, Branch, Little River (MBLR) Watershed shoreland survey of non-point source pollution. Wells National Estuarine Research Reserve Wells, ME. 61 pp.

Lincoln, J.M. and D.M. FitzGerald. 1988. Tidal distortions and flood dominance at five small tidal inlets in southern Maine. Marine Geology 82: 133-148.

Linnell, S. 1994. A survey of impounded salt marshes in southern Maine. Masters thesis, Antioch New England Graduate School, Keene, NH. 88 pp.

Little, M.J. 1992. Little River watershed fish survey. 160 pp.

Little, M.J. 1995. The potential for the restoration of tidal salt marshes by restoring the tidal flow: an overview with reference to the salt marsh at Locke Road, Rye, New Hampshire. Masters thesis, Antioch New England Graduate School, Keene, NH. 108 pp.

Lubelczyk, C. and B.K. Cahill. 2005. Report on the results of surveys of vector mosquito species (Diptera:Culicidae) in Cumberland and York Counties, Maine. July-October, 2005. 8 pp.

Lubelczyk, C., S.P. Elias, P.W. Rand, M.S. Holman, E.H. Lacombe and R.P. Smith, Jr. 2004. Habitat associations of *Ixodes scapularis* (Acari:Ixodidae) in Maine. Environmental Entomology 33(4): 900-906.

MacKenzie, R.A. 2003. Northern range extension for *Goeldichironomus devineyae* (Insecta: Diptera). Northeastern Naturalist 10(4): 465-467.

MacKenzie, R.A. 2004. Spatial and temporal patterns in insect emergence from a southern Maine salt marsh. American Midland Naturalist 153: 257-269.

MacKenzie, R.A. and M. Dionne. Ecological processes, energy pathways, and the impact of human activities on Maine marsh-estuarine secondary production: a salt marsh panne model. Report to Maine Sea Grant. Wells National Estuarine Research Reserve, Wells, ME. 55 pp.

Maine Department of Inland Fisheries and Wildlife. 2006. Maine Damselfly and Dragonfly Survey.

Maine Sea Grant. Managing Maine's beaches: A regional planning approach. Brochure. Maine Sea Grant. 6 pp.

Mariano, C.G. 1989. Wave-current interactions at Wells inlet and a comparison of hydraulics and sand circulation with Little River inlet. Masters thesis, Boston University, Boston, MA. 190 pp.

Mariano, C.G. and D.M. FitzGerald. 1989. Sediment transport patterns and hydraulics at Wells inlet, Maine. Boston University, Boston, MA. 143 pp.

Marvinney, R. 2002. Review of monitoring data, Wells Harbor scientific review panel. Unpublished report. Maine Geological Survey, Augusta, ME. 5 pp.

Marvinney, R. 2003. Review of monitoring data, Wells Harbor scientific review panel. Unpublished report. Maine Geological Survey, Augusta, ME. 8 pp.

McMullin, G. 1999. High intensity soil survey: Wells National Estuarine Research Reserve. Wells National Estuarine Research Reserve, Wells, ME. 53 pp.

Milbury, C. A. 1995. Distribution and abundance of the softshell clam, *Mya arenaria* and other macroinfauna in two contrasting estuaries at the Wells National Estuarine Research Reserve. Report to NOAA Sanctuaries and Reserves Division. Wells National Estuarine Research Reserve, Wells, ME. 184 pp.

Milbury, C. A. 1997. The distribution of the soft-shell clam *Mya arenaria* (Linnaeus) recruits with the Webhannet estuary, Wells, Maine. Honors Senior Thesis, University of New Hampshire, Durham, NH. 61 pp.

Montello, T.M., D.M. FitzGerald, S. van Heteren, D.W. Caldwell and L.K. Fink. 1992. Stratigraphy and evolution of the barrier system along the Wells-Ogunquit embayment in Southern Maine. Boston University, Boston, MA. 230 pp.

Morgan, P.A. 2000. Conservation and ecology of fringing salt marshes along the Southern Maine / New Hampshire coast. Dissertation, University of New Hampshire, Durham, NH. 138 pp.

Morgan, P.A. and F.T. Short. 2000. Functions and values of salt marshes in Northern New England: a comparison of fringing marshes and meadow marshes. Report to National Oceanic and Atmospheric Administration, Wells National Estuarine Research Reserve, Wells, ME. 78 pp.

Morgan, P.A. and F.T. Short. 2002. Using functional trajectories to model constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire. Restoration Ecology 10: 461-473.

Morgan, P.A., L. Curci, C. Dalton and J. Miller. 2005. Assessing the health of fringing salt marshes along the Fore River and its tributaries. Natural Resource Damage Trustees, Maine Department of Environmental Protection, Portland, ME. 45 pp.

Morgan, P.A., M. Dionne, R. MacKenzie and L. Curci. 2005. Ecological functions and values of fringing salt marshes susceptible to oil spills in Casco Bay, Maine. Maine Oil Spill Advisory Council, Maine Sea Grant, Orono, ME. 67 pp.

Moser, S. 1998. Talk globally, walk locally: the cross-scale influence of global change information on coastal zone management in Maine and Hawai'i. Global Environment Assessment Project, John F. Kennedy School of Government, Harvard University, Cambridge, MA. 74 pp.

Murphy, S.C. 1991. The ecology of estuarine fishes in southern Maine high salt marshes; access corridors and movement patterns. Masters thesis, University of Massachusetts, Amherst, MA. 103 pp.

Nature Conservancy, Maine Chapter. 2004. A conservation plan for the Mount Agamenticus region: a community plan for the future. The Nature Conservancy, Brunswick, ME. 51 pp.

Neckles, H.A. and M. Dionne. 2000. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine, a GPAC Workshop Report to the Commission for Environmental Cooperation. Wells National Estuarine Research Reserve, Wells, ME. 29 pp.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum and E. Hutchins. 2002. A monitoring protocol to assess tidal marshes at local and regional scales. Restoration Ecology 10(3): 556-563.

Nelson, B.W. and L.K. Fink. 1980. Geological and botanical features of sand beach systems in Maine. Maine State Planning Office, Augusta, ME 169 pp.

Newell, S.Y. and D. Porter. 2000. Microbial secondary production from salt marsh-grass shoots, and its known and potential fates. *In* Concepts and Controversies in Tidal Marsh Ecology. *Edited by* Weinstein, M. and D.A. Kreeger. Kluwer Academic, Norwell, MA. p. 159.

Orringer, S., R. S. and N. Sullivan. 1995. A survey of migratory fishes in the Little River estuary and its watershed. Draft final data report. Institute of Museum Services, Silver Spring, MD. 34 pp.

Owen, B. and S. White. 2005. National Estuarine Research Reserve System 10th Anniversary Report on the System-wide Monitoring Program (SWMP) Data Applications: 1995 – 2005. National Oceanic and Atmospheric Administration Estuarine Reserves Division, Silver Spring, MD.

Pennings, S.C. and M.D. Bertness. 2001. Salt marsh communities. *In* Marine Community Ecology. *Edited by* M.D. Bertness, S.D. Gaines and M.E. Hay. Sinauer, Sunderland, MA. pp. 289-316.

Pennings, S.C. and B.R. Silliman. 2005. Linking biogeography and community ecology: latitudinal variation in plant-herbivore interaction strength. Ecology 86(9): 2310-2319.

Pennings, S.C., E.L. Siska and M.D. Bertness. 2001. Latitudinal differences in plant palatability in Atlantic coast salt marshes. Ecology 82(5): 1344-1359.

Pennings, S.C., E.R. Selig, L.T. Houser and M.D. Bertness. 2003. Geographic variation in positive and negative interactions among salt marsh plants. Ecology 84(6): 1527-1538.

Pratt-Decker, V.W. 2005. York River Watershed nonpoint pollution survey and watershed management plan. Wells National Estuarine Research Reserve, Wells, ME. 85 pp.

Priesler, R.K., K. Wasson, W.J. Wolff and M.C. Tyrrell. 2005. Invasions of estuaries versus the adjacent open coast: a global perspective. *In* Marine bioinvasions: ecology, conservation and management perspectives. *Edited by* G. Rilov and J. Crooks. In review.

Quigley, W.C. 1992. A study of surface zonation of foraminifera at Wells marsh, Wells, Maine. Boston University, Boston, MA. 39 pp.

Rand, P.W., E.H. Lacombe, R.P. Smith, Jr. and J. Ficker. 1998. Participation of birds (Aves) in the emergence of Lyme disease in southern Maine. Journal of Medical Entomology 35(3): 270-276.

Rand, P.W., E.H. Lacombe, R.P. Smith, Jr., K. Gensheimer and D.T. Dennis. 1996. Low seroprevalence of human Lyme disease near a focus of high entomologic risk. American Journal of Tropical Medicine and Hygiene 55: 160-164.

Rand, P.W., M.S. Holman, C. Lubelczyk, E.H. Lacombe, A.T. DeGaetano and R.P. Smith, Jr. . 2004. Thermal accumulation and the early development of *Ixodes scapularis*. Journal of Vector Ecology 29(1): 164-176.

Rand, P.W., R.P. Smith, Jr. and E.H. Lacombe. 1991. Canine seroprevalance and the distribution of *Ixodes dammini* in an area of emerging Lyme disease. American Journal of Public Health 81: 1331-1334.

Rich, S. 1991. Wildlife management plan for the Wells National Estuarine Research Reserve. Wells National Estuarine Research Reserve, Wells, ME. 54 pp.

Rich, S. 1992. A census of white-tailed deer (*Odocoileus virginianus*) on the Wells Reserve using night spotlighting and line transect sampling. Final Report. 32 pp.

Rits, M. 2003. Wave-current interaction, sediment transport, and the responses of a jettied channel to dredging, Wells Inlet, Maine. Masters thesis, Boston University, Boston, MA. 328 pp.

Salgado, C.S. and S.C. Pennings. 2005. Latitudinal variation in palatability of salt-marsh plants: are differences constitutive? Ecology 86(6): 1571-1579.

Sebold, K.R. 1998. The low green prairies of the sea: economic usage and cultural construction of the Gulf of Maine salt marshes. Dissertation, University of Maine, Orono, ME. 332 pp.

Shipp, R.C. 1989. Quaternary stratigraphy of the inner continental shelf and adjacent coastal region of Maine. Dissertation, University of Maine, Orono, ME. 832 pp.

Short, F.T. 1988. Gradients in salt marsh productivity in the Wells National Estuarine Research Reserve. NOAA Technical Memorandum, NOS MEMD 16, Washington, DC. 64 pp.

Short, F.T. 1992. Declines of eelgrass in estuarine reserves along the east coast, U.S.A: problems of pollution and disease; and management of eelgrass meadows in East Coast research reserves. NOAA NOS Sanctuaries and Reserves Division, Silver Spring, MD. 112 pp.

Shriver, G. 2002. Conservation of salt marsh birds along the New England coast. Dissertation, Syracuse University, Syracuse, NY. 144 pp.

Sieracki, M.E. and C. Sieracki. 2003. Application of a continuous imaging flow cytometer for monitoring estuarine microplankton. Cooperative Institute for Coastal and Estuarine Environmental Technology. Durham, NH. 14 pp.

Siska, E.L., S.C. Pennings, T.L. Buck and M.D. Hanisak. 2002. Latitudinal variation in palatability of salt-marsh plants: which traits are responsible? Ecology 83(12): 3369-3381.

Slovinsky, P.A. and S.M. Dickson. 2005. Impacts of future sea level rise on the coastal floodplain. Maine Coastal Program, Maine State Planning Office, and National Oceanic and Atmospheric Administration. 27 pp.

Smith, G.W. 1982. End moraines and the pattern of last ice retreat from central and south coastal Maine. *In* Late Wisconsinian glaciation of New England. *Edited by* G.J. Larson and B.D. Stone. Kendall-Hunt. pp. 195-209.

Smith, G.W. 1985. Chronology of late Wisconsinian deglaciation of coastal Maine. *In* Late pleistocene history of northeastern New England and adjacent Quebec. *Edited by* Borns, H.W., P. LaSalle and W.B. Thompson. Geological Society of America Special Paper 197.

Smith, M. 2003. Watershed conservation strategies: Merriland River, Branch Brook and Little River (MBLR) watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. 2003. Watershed conservation strategies: Ogunquit River Watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. 2003. Watershed conservation strategies: Cape Neddick River watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. 2003. Watershed conservation strategies: Nonesuch River watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. 2003. Watershed conservation strategies: Spruce Creek watershed. Wells National Estuarine Research Reserve, Wells, ME. 24 pp.

Smith, M. 2003. Watershed conservation strategies: Webhannet River watershed. Wells National Estuarine Research Reserve, Wells, ME. 25 pp.

Smith, M. and H. True. 2004. Merriland River, Branch Brook, and the Little River (MBLR.): nonpoint source pollution management plan. Wells National Estuarine Research Reserve, Wells, ME. 55 pp.

Smith, M. and H. True, 2004. Merriland River, Branch Brook, and Little River (MBLR) watershed nonpoint source pollution management plan. Wells National Estuarine Research Reserve, Wells, ME. 48 pp.

Smith, R.P., P.W. Rand and E.H. Lacombe. 1990. Potential for Lyme disease in Maine: deer survey of distribution of *Ixodes dammini*, the tick vector. American Journal of Public Health 80: 333-335.

Smith, R.P., E.H. Lacombe, P.W. Rand and R. Dearborn. 1992. Diversity of tick species biting humans in an emerging area for Lyme disease. American Journal of Public Health 82: 66-69.

Spahr, T. and C.D. Kennie. 2005. Incorporating small streams and brooks into developing landscapes. Wells National Estuarine Research Reserve, Wells, ME. 57 pp.

St. Onge, S. 1995. Groundwater monitoring and marshland restoration on Drake's Island, at the Wells National Estuarine Research Reserve, Wells, Maine. Boston College, Boston, MA. 13 pp.

Tary, A.K., D.M. FitzGerald and I.V. Buynevich. 2001. Late Quaternary evolution of a marine-limit delta plain, southwest Maine. *In* Deglacial history and relative sea level changes, northern New England and adjacent Canada. *Edited by* T.K. Weddle and M.J. Retelle. Geological Society of America, Special Publication 351. pp. 125-149.

Taylor, P.H. 2005. Salt Marshes of the Gulf of Maine. Gulf of Maine Council on the Marine Environment. 4pp.

Taylor, P.H. 2007. Salt marshes in the Gulf of Maine: human impacts, habitat restoration, and long-term change analysis. Gulf of Maine Council on the Marine Environment. 45 pp.

Theodose, T.A. 1999. Nutrient availability, nutrient limitation, and species diversity in salt marsh forb communities. New England Estuarine Research Society Spring Meeting.

Theodose, T.A. and J. Martin. 2003. Microclimate and substrate quality controls on nitrogen mineralization in a New England high salt marsh. Plant Ecology 167: 213-221.

Theodose, T.A. and J.B. Roths. 1999. Relationships between nutrient availability, stress, and diversity on two New England salt marshes. Plant Ecology 143: 219-228.

Timson, Schepps & Peters Inc. 1989. Analysis of salt marsh shoreline changes, Webhannet River estuary, Wells, Maine. report to Town of Wells, Wells, ME. 14 pp.

Timson, B.S. 1977. A handbook of coastal marine geological environments of the Maine coast. Maine Department of Conservation and Maine State Planning Office, Augusta, ME.

Timson, B.S. and D. Kale. 1976. Historical changes of the Webhannet River inlet. U.S. Army Corps of Engineers, New England Division.

Timson, B.S., D. Pickart and G. Pickart. 1989. Sand transport budget Wells Harbor and adjacent beaches. Timson, Schepps & Peters, Inc., Hallowell, ME. 61 pp.

True, H. 2005. Ogunquit River watershed; shoreland survey of non-point source pollution. Wells National Estuarine Research Reserve, Wells, ME. 46 pp.

True, H. 2006. Spruce Creek watershed non-point source pollution survey. Wells National Estuarine Research Reserve, Wells, ME. 36 pp.

Tyrrell, M.C. 2005. Gulf of Maine habitat primer. Gulf of Maine Council on the Marine Environment. 54 pp.

Tyrrell, M.C. and J.E. Byers. Do artificial substrates favor nonindigenous fouling species over natives? Journal of Experimental Marine Biology and Ecology. In press.

Tyrrell, M.C., P.A. Guarino and L.G. Harris. 2006. Predatory impacts of two introduced crab species: inferences from microcosms. Northeastern Naturalist 13(3): 375-390.

Vadas, R.L., P. Garwood and W. Wright. 1998. Production, nutrition, and ecological health of the Wells Salt Marshes. NOAA Technical Memorandum, NOS MEMD 20, Washington, DC. 86 pp.

van der Koppel, J. and C.M. Crain. Scale-dependent positive and negative interactions lead to regular spatial patterning in marsh vegetation. The American Naturalist. In press.

Vaughn, J.M. and J.F. Novotny. 1991. Microbial contamination in the Webhannet River estuary. University of New England, Biddeford, Maine. 131 pp.

Vincent, R. 1993. The Little River marsh: a survey of the plant communities along the upland border. Wells National Estuarine Research Reserve Wells, ME. 32 pp.

Wade, S.D. 1999. Effects of tidal restriction on elevation and plant communities in five tidal marshes in Wells and Kennebunk, Maine. Masters thesis, Antioch New England Graduate School, Keene, NH. 72 pp.

Ward, A.E. 1999. Maine's coastal wetlands: types, distribution, rankings, functions, and values. State of Maine Department of Environmental Protection, Augusta, ME. 100 pp.

Ward, L.G. 1993. Precipitation, streamflow, and water characteristics (physical and chemical) of the Webhannet River estuary, Wells, Maine. Jackson Estuarine Laboratory, University of New Hampshire Department of Earth Sciences, Durham, NH. 101 pp.

Ward, L.G. 2004. Variations in physical properties and water quality in the Webhannet River Estuary (Wells National Estuarine Research Reserve, Maine). Journal of Coastal Research 45: 39-58.

Wells National Estuarine Research Reserve. 2007. Reserve Management Plan, Wells National Estuarine Research Reserve, Wells, ME.

Wells National Estuarine Research Reserve. 1994. A survey of meiobenthos and ichthyoplankton in two contrasting estuaries at the Wells National Estuarine Research Reserve, Maine. Draft final data report to National Oceanic and Atmospheric Administration Wells National Estuarine Research Reserve, Wells, ME. 11 pp.

Wells National Estuarine Research Reserve. 2002. Fish species of the Wells National Estuarine Research Reserve. Brochure, Wells, ME. 2 pp.

Wells National Estuarine Research Reserve. 2002. Watershed inputs of non-point source pollution to the Webhannet estuary. Report to Gulf of Maine Council on the Marine Environment. Wells National Estuarine Research Reserve, Wells, ME. 40 pp.

Wells National Estuarine Research Reserve. Ogunquit River watershed management plan. In preparation.

Wenner, E. L., A.F. Holland, M.D. Arendt, Y. Chen, D. Edwards, C. Miller, M. Meece and J. Caffrey, 2001. A synthesis of water quality data from the National Estuarine Research Reserve's system wide monitoring program. Final report to CICEET (grant NA97OR0209) National Ocean Service, Office of Ocean and Coastal Resource Management. 276 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S. Jones. 2003. Microbial source tracking in two southern Maine watersheds: Webhannet River watershed report. Wells National Estuarine Research Reserve, Jackson Estuarine Laboratory, Wells, ME. 66 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S.J. Jones. 2003. Microbial source tracking in two southern Maine watersheds: executive summary for Webhannet River watershed. Wells National Estuarine Research Reserve Wells, ME. 6 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S.J. Jones. 2004. Microbial source tracking in two southern Maine watersheds: executive summary for Merriland River, Branch Brook, and Little River (MBLR) watershed. Wells National Estuarine Research Reserve Wells, ME. 7 pp.

Whiting-Grant, K., F. Dillon, C. Dalton, M. Dionne and S.J. Jones. 2004. Microbial source tracking in two southern Maine watersheds: Merriland River, Branch Brook, and Little River (MBLR) watershed report. Wells National Estuarine Research Reserve, Wells, ME. 56 pp.

Whitlow, L., N.A. Rice and C. Sweeney. 2003. Native species vulnerability to introduced predators: testing an inducible defense and a refuge from predation. Biological Invasions 5: 23-31.

Whitlow, W.L. 2002. Changes in native species after biological invasion: effects of introduced green crabs on native soft-shell clams and an estuarine community. Dissertation in Ecology and Evolutionary Biology. University of Michigan, Ann Arbor, MI. 310 pp.

Whitlow, L., N.A. Rice, and C. Sweeney. 2003. Native species vulnerability to introduced predators: testing an inducible defense and a refuge from predation. Biological Invasions 5: 23-31.

Widoff, L. 1985. The vegetation of the Wells National Estuarine Sanctuary. Maine State Planning Office, Augusta, ME. 47 pp.

Wilson, J.A. 2001. Scientific uncertainty, complex systems and the design of common pool institutions. *In* The drama of the commons. National Research Council, Washington, DC.

Wilson, K.R. 2006. Ecogeomorphology of salt pools of the Webhannet estuary, Wells, Maine, USA. Masters thesis, University of Maine, Orono, ME. 98 pp.

Yozzo, D.J., M.S. Laska, L. Morales, J.L. Prockup and P.J. Spidahl. 2003. Restoration program assessment for the National Estuarine Research Reserve System (NERRS). National Oceanic and Atmospheric Administration Estuarine Reserves Division. 54 pp.

Glossary

Hannah Wilhelm

The preceeding chapters include work from many disciplines. The definitions below are intended to provide clarification of technical language used by the authors, but do not include names of animals or specific taxonomic groups.

abiotic (*adj*) Non-living. Abiotic drivers are physical properties, such as salinity, wind speed, or the presence of ice, that influence what lives in a particular habitat.

accrete (*v*) To add on or grow. Accretion is the process of growing by gradual additions. Vertical accretion of a salt marsh is the process of soil buildup, due to accumulation of organic matter in particular, and to sediment deposition in general, that allows the marsh surface to rise over time.

adventitious (*adj*) In biology, refers to something growing in an unusual or unexpected location.

algae (*n*) Aquatic organisms that obtain energy through photosynthesis. Algae are not classified as plants because they lack roots, stems, and leaves. Macroalgae are commonly known as seaweed, and microalgae suspended in the water column are called phytoplankton.

algal bloom (*n*) Rapid proliferation of algae, usually following an influx of nutrients to water.

anadromous (*adj*) Describes the migratory behavior of organisms that spend the majority of life in marine waters and eventually moving to fresh and / or brackish waters to breed.

anoxic (*adj*) Characterized by the absence of oxygen. Anoxia is the associated state. An anoxic event is a sudden depletion of oxygen, usually in a body of water. An anoxic event can occur when a proliferation of organisms die and decompose, using all the available oxygen.

anthropogenic (*adj*) Created by humans.

arcuate (*adj*) Arch- or bow-shaped.

avian (*adj*) Of or relating to birds.

back-barrier (*n*) The area sheltered behind a barrier beach.

barrier beach (*n*) A ridge of land, made of sand, roughly parallel to the mainland and separated from it by water.

baseflow (*n*) The usual amount of water flowing through a river or stream.

benthic (*adj*) Bottom-dwelling. Benthic organisms live in sediments that underlie a body of water.

benthos (*n*) The substrate underlying the bottom of a body of water, or the collection of organisms that live there.

biogenic habitat (*n*) A habitat whose structure is created or shaped by plants and / or animals.

biomass (*n*) The mass of living organisms (usually measured within a specific area).

biotic (*adj*) Of or derived from a living organism.

biphasic (*adj*) Having two distinct phases. For amphibians, refers to a life cycle that takes place partly on land and partly in the water.

brackish (*adj*) Referring to water, somewhat salty. See oligohaline.

byssal (*n*) Silky threads connecting a mollusk to its substrate.

carapace (*n*) A hard covering on an animal's back (e.g., a turtle's shell).

catadromous (*adj*) Describes the migratory behavior of organisms that spend the majority of life in fresh water, but move to marine or estuarine environments to spawn.

chemocline (*n*) Referring to estuaries, the boundary between fresh water and overlying salt water when the water column is stratified (layered).

circadian rhythm (*n*) The daily activity cycle exhibited by living things.

clonal (*n*) Produced via asexual reproduction.

coastal shelf (*n*) The submerged part of a continental margin (edge), which is shallow in comparison to the deep ocean floor. The shelf is separated from the deep ocean by the steep continental slope.

coastal transgression (*v*) Movement of the coastline inland.

consumer (*n*) An organism that obtains its energy by eating other organisms. See heterotrophic.

core sample (*n*) A cylindrical sample of soil collected from the surface downward; soil horizons (layers) remain ordered.

cryptogenic (*adj*) Having an unknown origin.

demersal (*adj*) Dwelling on or near the bottom of a body of water.

desiccate (*v*) To dry out.

detritus (*n*) Loose debris. Often refers to decaying organic matter fallen to the bottom of a body of water.

diadramous (*adj*) Describes the migratory behavior of organisms that live the majority of life in either fresh water or salt water and eventually move to the other to breed. See anadramous and catadramous.

dioxin (*n*) A toxin belonging to a family of hydrocarbons having the formula $C_{12}H_4Cl_4O_2$.

discharge (*n*) the quantity of water that flows through or out of a river.

downdrift shoreline erosion (*n*) Removal of sediment from a shoreline when the ebb tide carries it away from a tidal delta. See tidal delta.

dredge (*v*) To remove sediment from the bottom of a body of water.

drumlin (*n*) An oval-shaped hill made of glacial drift (mixed sand, gravel, boulders, etc. deposited by a glacier).

ebb tide (*n*) The outgoing tide; water leaving the shore.

ecad (*n*) An alternate growth form of algae such as *Aschophyllum nodosum*, Ecads form thick mats among the roots of *Spartina alterniflora* in the low marsh zone.

ecosystem (*n*) A collection of living organisms plus their abiotic environment.

ecosystem services or ecosystem functions (*n*) A description of the way a component of an ecosystem supports living things in that ecosystem. For example, salt marsh peat filters water, removing contaminants that might otherwise disturb marine life.

ecosystem state or ecosystem status (*n*) A description of the general patterns and processes existing within an ecosystem.

ectothermic (*adj*) Needing to obtain heat from an external source to survive.

egest (*v*) To excrete. The opposite of ingest.

embayment (*n*) An indentation in a coastline; similar to a bay, but not as concave.

emergent vegetation (*n*) Plants and algae that grow in intertidal areas.

endemic (*adj*) Constantly present in and uniquely associated with a particular location. Endemic species are found only in a certain area. Endemic diseases are present in many individuals of a population in a specific area. Endemism is the associated state.

enzootic (*adj*) Afflicting animals in a particular location. Used to describe a disease.

epibenthic (*adj*) Of or relating to the area on the surface of bottom sediments in a body of water.

epifauna (*n*) Animals that live on the surface of a substrate, such as soil or rock.

epiphyte (*n*) A non-parasitic plant that grows on another plant. Epiphytic is the adjective form.

esker (*n*) A long hill of gravel and sand, formed a glacial meltwater stream.

estuary (*n*) The area where a river meets the sea.

euryhaline (*adj*) Able to live in water having a wide range of salinities.

eustatic (*adj*) Of or relating to eustasy, which is a change in global sea level.

eutrophification (*n*) A multi-stage process of harmful nutrient enrichment in a body of water. Excess nutrients cause an algal bloom, which may block the light reaching submerged vegetation, causing it to die. Proliferation of decomposing organisms then leads to anoxic conditions.

evapotranspiration (*n*) The collection of processes through which water escapes plants and other cover on the earth's surface through evaporation (changing from liquid to gas).

exothermic vertebrate (*n*) A cold-blooded animal with a backbone, i.e., a reptile or amphibian. See ectothermic.

fallow (*adj*) Lying dormant; not in use. Describes agricultural land.

fecal coliform (*n*) A type of bacteria present in feces (including human feces) that can be grown in culture. High levels of fecal coliform may indicate contamination of water by sewage.

flocculation (*n*) The process of clumping together.

flood tide (*n*) The rising tide; incoming water.

floodplain (*n*) An area that is periodically inundated with water.

food web (*n*) A theoretical tool that summarizes food choices of various species.

forb (*n*) A broad leafed-plant; not a grass. Forb zones and forb pannes are characterized by the presence of forbs.

fouling (*adj*) Refers to species that attach to man-made structures in the water (boats, docks, etc.), or to communities of these species.

freshet (*n*) An influx of fresh water.

fringing marsh (*n*) A narrow marsh that forms along the upland edge of estuarine channels and open water protected from strong waves.

furan (*n*) An organic compound having the formula C_4H_4O.

genotype (*n*) A version of the genetic makeup of an organism, referring to a specific trait or set of traits.

geographic information systems (GIS) (*n*) A computer tool for cataloguing and displaying maps and associated information.

geomorphology (*n*) The study of landforms and their origins. The adjective form is geomorphologic.

georeferenced (*adj*) Of maps or aerial photographs, synchronized with actual locations on earth.

glacial rebound (*n*) See isostatic rebound.

glacial till (*n*) Cobbles, boulders, gravel and sand deposited during glacial melting.

glaciomarine (*n*) Of or relating to a place where glacial ice is, or was, touching the ocean.

groin (*n*) A small jetty built to prevent erosion of beach sand.

groundwater (*n*) Water present in openings or streams within soil or rock.

habitat restoration (*n*) An effort to return a habitat to an earlier, usually less developed, state.

halophyte (*n*) A salt-tolerant organism.

head of tide (*n*) The farthest extent of tidal influence in a river.

headland (*n*) An outcropping of land, underlain by bedrock, that extends into the ocean.

herbivorous (*n*) Plant-eating.

herpetology (*n*) The study of reptiles and amphibians.

heterotrophic (*n*) Not self-sustaining. heterotrophic organisms, or consumers, must get energy by oxidizing the organic compounds present in another organism. Unlike autotrophic organisms, they cannot create their own food from inorganic compounds. See organic and inorganic.

high marsh (*n*) In Maine salt marshes, the area of vegetated marsh that is above the level of mean high water.

Holocene (*n*) The name of the current geologic epoch.

holoplankton (*n*) Species that are planktonic for their entire lives.

hydroperiod (*n*) The length of time during which a wetland is covered by water.

ice block depression (*n*) A dip or hole formed where a glacier left behind a chunk of ice, partially buried in sediment, that later melted, leaving a space.

ice scar (*n*) An area of the marsh surface where ice has passed, scraping away vegetation, and leaving a ring of dead vegetation surrounding the bare soil.

impervious surface (*n*) An area of land that water cannot easily penetrate (e.g., parking lots, roofs).

indicator species (*n*) A species whose survival or abundance can provide a shorthand for assessing ecosystem state.

inducible defense (*n*) A defense mechanism, often a change in the body structure of a prey species, activated by a (typically chemical) cue from another organism.

infauna (*n*) Animals living in benthic sediments.

intertidal (*adj*) Located in the area of the coast defined by the full tidal range, i.e., in the floodplain of the tides.

invasive (*adj*) New to a region and reproducing rapidly, outcompeting other species.

invertebrate (*n*) An animal having no backbone.

isostatic (*adj*) Occurring as expected according to the principal of isostasy, which states that the earth's crust exists in an equilibrium with the mantle, and when one area of the crust is depressed (e.g., by glacial ice), another area will rise to counterbalance it.

isostatic rebound (*n*) The rising of continental crust after the retreat of a glacier.

isotope (*n*) Different isotopes of the same chemical element have differing atomic weights, but the same number of protons. For example, ^{12}C is the most common isotope of carbon, and ^{14}C is a less common, radioactive, isotope of carbon used to calculate the age of organic materials. The nucleus of a ^{12}C atom has six protons and six neutrons, while that of ^{14}C has six protons and eight neutrons.

jetty (*n*) A structure extending into a body of water, usually created to protect a channel used for navigation.

kame (*n*) A ridge or mound of sand and / or gravel left by a retreating glacier.

keystone (*adj*) Refers to a species whose presence is critical to the stability of an ecosystem.

lacustrine (*adj*) Of or relating to lakes. Of fossils or buried strata, refers to something that formed along the bottom or shores of a lake.

latitudinal (*adj*) Of or relating to location along a North-South axis.

linear regression (*n*) A graph showing the dependence of one variable on another.

lithosphere (*n*) The earth's crust; the outermost layer of the earth.

loam (*n*) One of the basic soil types. Contains sand, silt, clay in approximately equal proportions.

low marsh (*n*) In Maine salt marshes, the area nearest the seaward edge and near tidal creeks and channels, characterized by low elevation, extended tidal inundation, and the growth of *Spartina alterniflora*.

macroalgae (*n*) Algae large enough to be visible with the naked eye.

macrofauna (*n*) Animals large enough to be visible to the naked eye.

macroinvertebrate (*n*) An animal having no backbone that is large enough to see with the naked eye.

macrotidal (*adj*) Having a wide tidal range.

marker horizon (*n*) A reference soil layer used to quanitfy sediment deposition on the marsh surface.

mast (*n*) Seeds of forest trees (e.g., acorns, beech nuts). A mast year, a year with an unusually large crop of seeds, occurs intermittently, leading to a rise in the population of seed-eating animals such as squirrels and white-tailed deer.

meadow marsh (*n*) A large expanse of salt marsh, often located behind a barrier beach.

mean high water (*n*) The average elevation of water at high tide.

mean low water (*n*) The average elevation of water at low tide.

meiofauna (*n*) Very small benthic organisms that pass through a 0.5 mm sieve, but cannot pass through a 0.045 mm sieve.

meroplankton (*n*) Species that are plankton for only one part of their life cycle.

mesohaline (*adj*) moderate salinity; having a salinity of 5 to 18 parts per thousand.

microbial source tracking (*n*) research aimed at discovering the species sources of bacterial contamination in water.

micropaleontology (*n*) The study of microscopic fossils.

microtopography (*n*) The miniature landscape of the salt marsh, created by small variations in elevation that result from deposition of sediment by ice and wrack by tides, and the movement of sediment by water.

mineralize (*v*) Of nitrogen in an ecosystem, to be transferred from an inorganic compound to an organic compound; to become available for use by plants and animals.

mist net (*n*) A net made of very fine mesh, nearly invisible and used to catch birds, bats, or other flying creatures without harming them.

monoculture (*n*) An stand of plants containing only one species or variety.

monotypic (*adj*) Consisting of only one genotype or phenotype (i.e., strain) of a species.

moraine (*n*) A ridge made by deposition of stones and sediment left by a retreating glacier.

morphological (*n*) Having to do with physical structure (shape and size). The morphology of an animal, plant, or habitat structure is a description of its extent, shape, and pattern.

native (*adj*) Of species, having lived in the area for approximately a century or more.

nekton (*n*) Any macroscopic, free swimming marine organism (e.g. fish).

Northeaster / Nor'easter (*n*) In the Gulf of Maine, a storm approaching from the northeast.

notochord (*n*) A structure similar to the spinal column that supports the bodies of species in the phylum Chordata that have no true spine.

nursery (*adj*) Describes habitat that serves as protection for juvenile organisms.

oligohaline (*adj*) Low salinity; brackish; refers to water having salinity of 0.05 to 0.5 parts per thousand.

ontogenetic (*adj*) Of or relating to the history and / or origin of a species. The ontogeny of a species is the history of its evolution and development.

outwash plain (*n*) In geology, the sloping area created by deposits of sand and gravel carried away from a glacier by streams of meltwater.

organic (*adj*) Containing the element carbon; of or derived from a living thing.

oxbow (*n*) A wide, looped bend in a river.

oxidation (*n*) The loss of electrons from a chemical compound, often leading to a change in its structure. Rusting of metal is an oxidative process. Bacteria use oxygen to metabolize organic matter, leaving only inorganic matter behind.

panne (*n*) See pool *vs.* panne.

peat (*n*) Soil formed in areas constantly or periodically saturated with water; high organic matter content.

pelagic (*adj*) Living in the water column, but not in bottom waters.

photosynthetically active radiation (PAR) (*n*) The range of wavelengths of light that can be used for photosynthesis.

phylogenetic (*adj*) Of, relating to, or caused by phylogeny (evolutionary history).

phytoplankton (*n*) Plankton that get energy through photosynthesis.

pine plantation (*n*) An area that was planted with (usually ordered rows of) pine trees to be harvested for timber.

piscivorous (*adj*) Fish-eating.

plankton (*n*) Any of several small organisms that drift passively in the water column. A planktivore is an animal that primarily eats plankton, and the adjective planktonic means of or relating to plankton.

polyhaline (*adj*) moderate salinity; having a salinity of 18 to 30 parts per thousand (ppt).

polyploidy (*n*) The condition of having an extra set of chromosomes.

pool *vs.* **panne** (*n*) A salt marsh pool is a high marsh indentation that remains water-filled at low tide. A panne is an area having exposed soil that drains at low tide. Sometimes panne is used to describe a shallow pool, but this usage is not preferable.

primary producer (*n*) An organism such as a plant, alga, or bacterium that can obtain its energy without eating another organism.

radiometric date (*n*) A calculation of the age of an object made using measurements of radioactive decay. See isotope.

rating curve (*n*) A graph showing the relationship between the amount of water that flows past a certain point in a river and the depth of the river at that point. Using this graph, discharge can be estimated by measuring the stage. See discharge and stage.

rebound, glacial (*n*) See isostatic rebound.

redox (*adj*) Of or relating to oxidation and reduction, chemical reactions where one molecule loses electrons to another molecule. In salt marsh ecology, redox potential of soils is often measured in order to predict what chemical reactions may be occurring involving sulfur in the soil.

reference site (*n*) A comparatively undisturbed area used as a control for comparison in a field survey or experiment.

refugium (*n*) An area that has experienced little ecological alteration, allowing species to survive even if local extinction has occurred in surrounding areas. The plural is refugia.

relative sea level (*n*) A number describing the height of the ocean above a permanently fixed reference point.

relict (*adj*) Refers to a remnant from an earlier time, such as a species or geologic feature.

revetment (*n*) A structure built to preserve the shoreline by protecting it from waves.

ribotype (*n*) A genetic analysis used to distinguish between different species or different bacterial strains.

risk cues (*n*) Signals, including chemical signals, that allow prey to detect the presence of a predator.

riverine (*adj*) Of, relating to, or near a river.

seawall (*n*) A wall or jetty built to prevent shoreline erosion.

Sediment Elevation Table (SET) (*n*) An instrument used to measure change in elevation of the marsh surface.

sedimentology (*n*) The study of the deposition, transport, and origin of sediments, soils, and sedimentary rock.

sessile (*adj*) Unmoving. Refers to organisms that live attached to a rock or other object.

shelf (*n*) See coastal shelf.

siphon (*n*) A tubular structure that filter-feeding organisms use to obtain their food.

sonde (*n*) An underwater data-collecting instrument.

species richness (*n*) The number of species found in a given area.

spring freshet (*n*) An influx of fresh water from spring rains and snowmelt.

stage (*n*) In hydrology, the height of a river or stream's surface above a fixed point.

stenohaline (*adj*) Able to tolerate only a narrow range of salinities.

stomata (*n*) Small openings (on leaves or stems) used by plants to exchange gasses with the surrounding environment.

stratigraphy (*n*) The arrangement of layers of the earth's crust.

supratidal (*adj*) Located in the area above the reach of most high tides.

taxonomist (*n*) A scientist specializing in the categorization of living things. Taxonomy is the science of biological classification.

telemetry (*n*) The delivery of data, via satellite, radio, mobile phone, etc., as it is collected.

terrane (*n*) A piece of the earth's crust, having different origin and composition than the surrounding bedrock, that previously collided and merged with the bedrock.

tidal creek (*n*) A creek running through a marsh, which fills with water at high tide, and loses water at low tide, leaving some exposed mud.

tidal delta (*n*) The opening of the main channel of an estuary.

tidal prism (*n*) The volume of water that flows into and out of an estuary.

tidal range (*n*) The distance between the lowest low tide and the highest high tide.

tidal restriction (*n*) Prevention of ocean water or other water influenced by tides, such as water draining to an estuary, from rising and falling. Caused by a dam, dike, road, or other barrier.

till uplands (*n*) Inland areas underlain by glacial till. See glacial till.

trait-mediated indirect effects (*n*) Indirect effects of a predator on its prey that are noticeable through changes of a specific characteristic, or trait in the prey. For example, snail's shells may grow thicker when green crabs are present.

transient species (*n*) In estuarine ecology, marine fish that spawn in estuaries, fish that use estuaries as a nursery ground, and marine fish that may visit estuaries as adults, in contrast with resident species, those that spend their whole lives in an estuary.

trophic (*adj*) Of or relating to the distribution and transfer of energy in an ecosystem. Trophic levels are the various levels in a food web. The first trophic level is made up of primary producers, usually plants or algae that obtain energy from the sun. The second trophic level consists of primary consumers (animals that eat plants or algae). Trophic transfer or trophic relay is the passing of energy from one organism to another (e.g., a fish eating a smaller fish).

turbidity (*n*) Cloudiness, usually of water. Turbid water is clouded with sediment or other suspended particles.

tussock (*n*) A tuft-like growth of a plant.

vascular plants (*n*) Plants having tubes (xylem and phloem) to carry water, such as trees, grasses, wildflowers, and ferns. A moss is an example of a non-vascular plant.

vector (*n*) An agent, such as insect or bacterium, that transmits a disease.

vegetative buffer or riparian buffer (*n*) The area alongside a body of water, if it is covered with plants, and the soil is not exposed. Riparian buffers protect a body of water because the plants and soils in the buffer zone take up nutrients and contaminants, absorb runoff and reduce soil erosion during precipitation events.

vernal pool (*n*) A small freshwater wetland that is only present for part of the year, often in the spring following heavy rains and snowmelt. Often found in or near forested areas.

vertical accretion (*n*) See accrete.

water column (*n*) The water below the surface and above the bottom sediments.

watershed (*n*) The area of land drained by a specified body of water (e.g., the Gulf of Maine watershed consists of all the land within which water flowing to any stream would eventually end up in the Gulf of Maine).

wrack (*n*) Plants or algae washed onto the beach or marsh surface.

$\bar{x}$ (*symbol*) Mean (average).

young of year (YOY) (*n*) The fish age class representing the first year of life.

zooplankton (*n*) The collection of small animals that live in the water column. Zooplankters are individual zooplankton.