Waterfowl Habitat Change over Five Decades in a Freshwater Tidal Ecosystem in Mid-Coast Maine

John Lichter[1,*], Mark E.H. Burton[1], Sarah L. Close[1], Juliana M. Grinvalsky[1], and Jaret Reblin[1]

Abstract - Merrymeeting Bay is a 4330-ha freshwater tidal ecosystem in mid-coast Maine that historically provided important stopover habitat for migrating waterfowl. To better understand a substantial decline in the number of ducks foraging in the ecosystem over the past fifty years, we reconstructed a history of environmental change using oral histories, aerial photography, and field experiments. Our studies revealed profound environmental change throughout the 20th century that likely influenced the capacity of the ecosystem to support migrating waterfowl. Ironically, the unregulated discharge of industrial and municipal wastes and high rates of sedimentation associated with land use in the middle decades of the 20th century probably enhanced the extent and productivity of intertidal, emergent plant communities including key forage plant species. However, over the past 30 years, primary wastewater treatment and regional reforestation have reduced the rates of nutrient loading and sedimentation, thereby diminishing the emergent vegetation. Reinforcing this decline in emergent vegetation, a precipitous decrease in submerged aquatic vegetation between 1956 and 1981 was likely related to extreme water turbidity. The collapse of subtidal aquatic vegetation would have reduced the variety and quantity of food items available to waterfowl. These local environmental changes coincided with regional declines in several duck species migrating along the Atlantic flyway. Therefore, both regional processes affecting the overall duck populations as well as local environmental change likely influenced the abundance of waterfowl using this site over the past 50 years.

Introduction

In 1905, Frank Noble and a companion rowed toward a large flock of *Anas rubripes* (Brewster) (American Black Duck) in Merrymeeting Bay, mid-coast Maine, not with the purpose of hunting ducks, but to experience the roar of thousands of birds rising simultaneously from the water. He described the flock as almost entirely comprised of Black Ducks and estimated the ribbon-shaped flock to be more than a mile in length (Noble 1905). At dawn, the pair rowed rapidly toward the ducks until "…the nearest straggler jumped, then those nearest followed and then the entire flock from end to end rose into the air with a roar that fairly shook the bay." This flock of ducks would have numbered in the tens of thousands, yet such abundance was not uncommon at that time. Noble recounted that the previous year (1904) was extremely good for hunting with unusually large flocks of migrating *Anas platyrhynchos* (L.) (Mallard), *Anas americana* (Gmelin) (Wigeon), *Aythya americana* (Eyton) (Redhead), and *Anas strepera* (L.) (Gadwall) foraging in Merrymeeting Bay, noting also that the dependable Black Duck was as common as usual.

[1]Environmental Studies Program, Bowdoin College, Brunswick, ME 04011. [*]Corresponding author - jlichter@bowdoin.edu.

Merrymeeting Bay has long been known as a key stopover for migrating waterfowl along the Atlantic flyway in mid-coast Maine (Spencer 1957). It is a freshwater, tidal ecosystem formed by the confluence of six rivers, 27 km inland from the mouth of the Kennebec River. The Abenaki name for the ecosystem—"Quabacook"—means duck-water place (McKeen 1853, Wheeler and Wheeler 1878). Anecdotes abound regarding the impressive abundance of waterfowl during the Colonial Era. In the 17^{th} century, ducks were so abundant that English settlers had to throw firebrands out over the water to scare them away in order to sleep at night (Wheeler and Wheeler 1878). In 1717, historian Samuel Penhallow witnessed the harvest, without the use of guns, of ≈4600 ducks by Native Americans on the lower Kennebec River. The ducks were herded into creeks and clubbed to death during the molt, when the adult birds could not fly away and the young were not yet able to fly (Penhallow 1726). Although market hunting in the 19^{th} century resulted in a steady decline of waterfowl populations along the Atlantic flyway (Walsh 1971), Merrymeeting Bay still attracted appreciable numbers well into the 20^{th} century (Mendall 1949, Noble 1905). In the 1940s through the 1970s, Merrymeeting Bay was promoted as the premier duck-hunting site in New England (Mendall and Spencer 1961, Spencer 1957). Today, veteran hunting guides recall flocks of Black Ducks, *Anas discors* (L.) (Blue-winged Teal), and *Anas crecca* (Gmelin) (Green-winged Teal) numbering in the tens of thousands. Between 1948 and 1957, more than 25,000 ducks were harvested annually by hunters on Merrymeeting Bay and its tidal tributaries, and the ecosystem accounted for 20 percent of all sales of duck stamps for inland duck hunting in the state (Mendall and Spencer 1961). As late as 1980, the ecosystem commonly supported as many as 40,000 ducks at one time on its lush vegetation (Spencer et al. 1980). Ironically, the period of abundant waterfowl between the 1940s and 1970s was also characterized by egregious industrial and municipal water pollution (Köster et al. 2007, Lawrance 1967, Walker 1931), which precipitated widespread hypoxia and fish kills (Lichter et al. 2006, MDEP 1979).

Today, the water quality of Merrymeeting Bay and its tributaries has improved dramatically (Lichter et al. 2006), but the number of ducks rarely exceeds a few thousand at any one time. Regional population decreases in several duck species along the Atlantic flyway likely contributed to this decline (e.g., Conroy et al. 2002, Wilkins et al. 2007). However, local environmental change may also have influenced the resources available for migrating ducks and geese, making the site more or less attractive than other sites along the coast. To understand the potential influence of local environmental change on the numbers of migrating waterfowl stopping over in Merrymeeting Bay, we interviewed eight veteran duck hunters along with a retired waterfowl biologist, from Maine's Department of Inland Fisheries and Wildlife (DIFW), who completed eleven consecutive years of field research on Merrymeeting Bay in the 1950s and 1960s. Collectively, this group had over three centuries of field experience on Merrymeeting Bay. Complementing these oral histories, we used nutrient-addition experiments and aerial photographic studies to document local vegetation change over the past five decades. Our long-term goal is to better understand the ecology and environmental history of Merrymeeting Bay and its tributaries to provide the information necessary for sound management and conservation.

Methods

Site description

Merrymeeting Bay is not a bay at all, but the upper, freshwater portion of the Kennebec estuary (Fig. 1). Two of Maine's largest rivers, the Androscoggin and the Kennebec, along with four minor rivers, the Eastern, Abagadasset, Cathance, and Muddy, come together 27 km inland to form this large freshwater, tidal ecosystem. The rivers drain a combined watershed of 24,460 km^2 or approximately one-quarter of Maine and part of New Hampshire and deliver a discharge ranging between 150 and 600 $m^3 sec^{-1}$ into Merrymeeting Bay. Water exits Merrymeeting Bay through a 215-m wide channel called the Chops into the lower Kennebec estuary. Substantial water flow through the Chops limits the intrusion and mixing of seawater from the lower Kennebec estuary into Merrymeeting Bay (Kistner and Pettigrew 2001, Wong and Townsend 1999). The lower Kennebec is a partially mixed, mesotidal estuary (Fenster et al. 2005). Of the 4330 ha total area, intertidal mud or sand flats comprise over 2000 ha or 47 percent of Merrymeeting Bay. These intertidal areas support emergent plant communities dominated by *Zizanea aquatica* (L.) (Wild Rice), *Schoenoplectus tabernaemontanii* (Gmelin) (Soft-stem Bulrush), *Bolboschoenus fluviatilis* (Torrey) (Gray) (River Bulrush), *Dulichium arundinaceum* (L.) (Three-way Sedge), *Sagittaria latifolia* (Willdenow). (Broad-leaf Arrowhead), and *Pontederia cordata* (L.) (Pickerelweed). Submerged aquatic plant communities are sparsely distributed and include *Vallisneria americana* (Michaux) (Wild Celery), *Potomogeton perfoliatus* (L.) (Perfoliate Pondweed), and *Najas flexilis* (Willdenow) (Nodding Water-nymph). These plant species along with the invertebrate communities they support would provide a diverse forage base for waterfowl (Martin et al. 1951, Mendall 1949, Mendall and Spencer 1961).

Reconstructing a history of local environmental change

Throughout the fall of 2005, we interviewed the veteran hunters and the DIFW biologist, recording their recollections of environmental change and trends in waterfowl populations. The information gathered from these oral histories was subsequently compared with quantitative evidence of environmental change and estimates of duck harvests to reconstruct a general history of the relationship between environmental change and migratory waterfowl use of Merrymeeting Bay. The waterfowl biologist, Howard (Skip) Spencer, Jr., spent eleven consecutive summers on Merrymeeting Bay between 1956 and 1967 studying the habitat properties important to ducks and geese, including vegetation, intertidal soils, and food choice. The motivation for his research was to better understand and improve the status of Merrymeeting Bay as waterfowl habitat (Spencer 1957).

To quantify local environmental change over the past 50 years, we compared current vegetation patterns with those described by past vegetation studies. Spencer's annual reports detailed the area of emergent and submerged aquatic plant cover based on aerial photography and extensive field surveys throughout the Merrymeeting Bay ecosystem including its tidal tributaries (Spencer 1959, 1966). To compare vegetation surveys conducted in 2003, in which stem densities were recorded per m^2, with Spencer's data, we duplicated his line-transect method for estimating percent cover of emergent plants and developed a regression relationship to convert his vegetation counts to stem densities per m^2.

In 1998, the James W. Sewall Company of Old Town, Maine, and Kleinschmidt Associates of Pittsfield, Maine were contracted by a local conservation organization, the Friends of Merrymeeting Bay, to provide aerial photography,

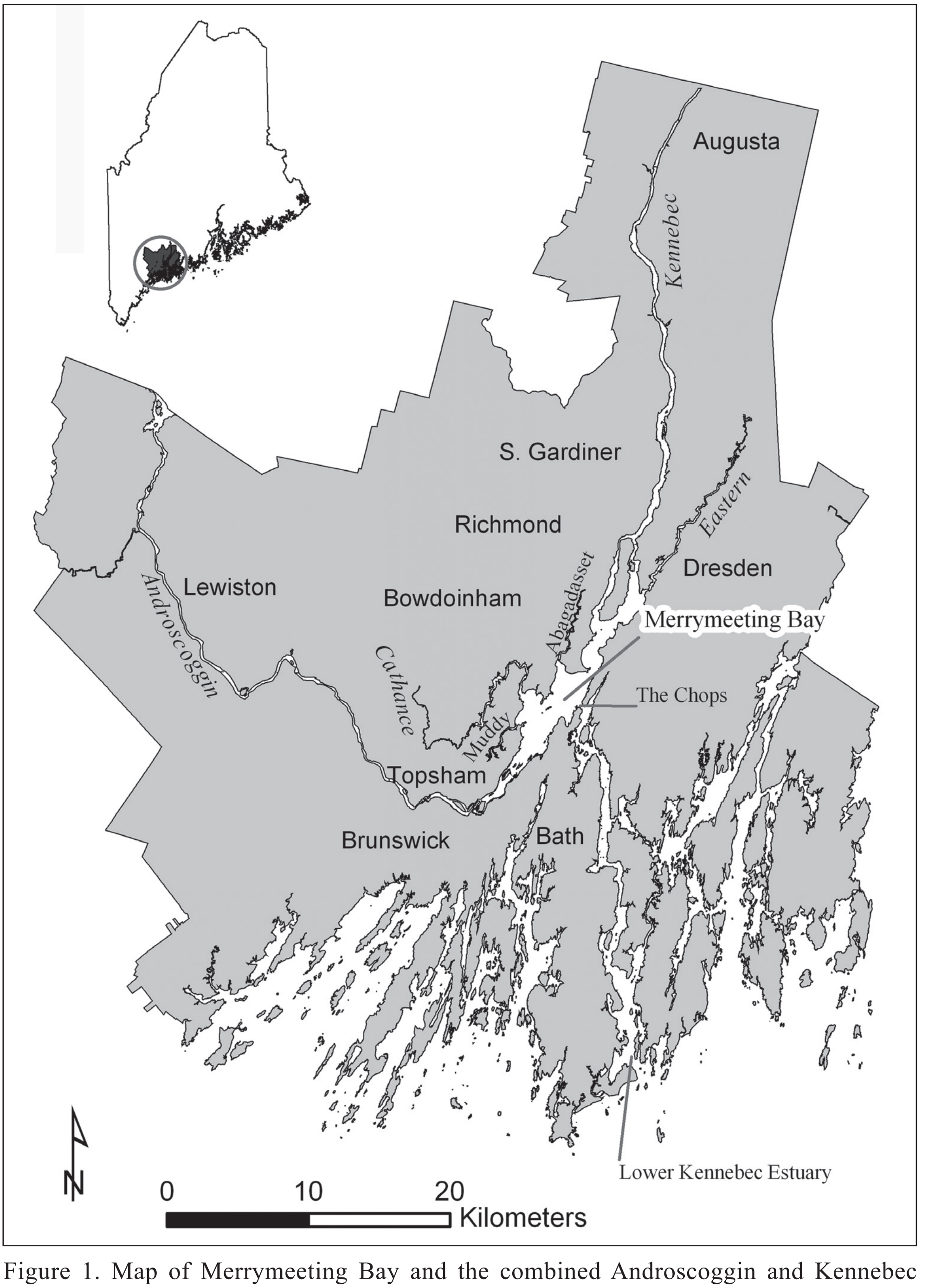

Figure 1. Map of Merrymeeting Bay and the combined Androscoggin and Kennebec watershed.

mapping, and analysis of vegetation trends in Merrymeeting Bay and the surrounding one-half mile of upland buffer area (Sewall Co. 2000). Our study duplicated the methods of previous aerial photographic studies in 1956 and 1981 to extend the time series with color infrared photographs taken at low tide. Vegetation mapping and analysis were completed using geographic information system (GIS) techniques coupled with field surveys to ground truth interpretation of the aerial photography. We examined these aerial and field studies to identify changes in forage plant species as well as overall changes in the emergent and submerged aquatic vegetation (SAV) over the 42-year period between 1956 and 1998. Of particular interest were changes in the spatial extent of Wild Rice as well as that of SAV. Because we found the quality of the 1956 color infrared photographs inadequate to confidently assess the area of SAV, we used Spencer's 1956 and 1961 estimates of the total area of submerged plant beds based on his field studies and some black and white aerial photography (i.e., Spencer 1959, 1966). To illustrate change in SAV area over the period from 1956 to 1998, we combined Spencer's estimates with information from the color infrared aerial photographs taken in 1981 and 1998.

Nutrient fertilization experiment

In 2004, we conducted a nitrogen and phosphorus fertilization experiment at three intertidal sites inhabited by emergent vegetation to determine the nature of nutrient limitation of plant productivity. The sites were chosen to represent coarse (i.e., sandy), intermediate (i.e., sand and silt), and fine-grained (i.e., silt) substrates. Experimental plots were laid out at the beginning of the growing season in early June at locations dominated by Wild Rice and in mixed emergent communities. Wild Rice seedlings were counted in individual treatment plots to account for initial differences in plant density. Nitrogen and phosphorus fertilizers were dispersed three times during the early portion of the growing season in a 2 x 2 factorial experimental design at each experimental site. To ensure that plants could access the additional nutrients, crystalline fertilizer pellets were worked into the intertidal substrate by hand. Approximately 6g NH_4-N m^{-2} and 3g PO_4-P m^{-2} were added each year. At the end of the growing season in September, Wild Rice plants were pulled out of the intertidal substrate and perennial plant species were clipped off at the surface of the intertidal substrate. The harvested plants were thoroughly washed, counted, and dried at 60 °C for seven days before weighing for dry biomass estimates. An ANOVA statistical model was used to test for significant effects of nutrient fertilizers and substrate texture after accounting for differences among the experimental plots in the initial density of Wild Rice seedlings (S-Plus 8.0, Insightful Corp.).

Waterfowl population counts

To estimate the population of ducks in the fall of 2005, we made several canoe trips into the large areas of emergent vegetation inhabiting the intertidal flats that usually host abundant foraging ducks, to count ducks as they left the water and circled overhead in the weeks prior to opening day of the migratory-bird hunting season. We also used a powerboat to survey a more extensive area of Merrymeeting Bay covering approximately three-fourths of the 4330-ha ecosystem, and made two flights in a small aircraft to photograph the numerous channels and open bodies of water in Merrymeeting Bay and along the Androscoggin and Kennebec rivers for the purpose of counting ducks in the photographs. Each of these flights lasted approximately two hours, allowing time to photograph the entire ecosystem.

Results

Vegetation change and waterfowl abundance

Interviews with the veteran duck hunters and Skip Spencer were genuinely informative about overall trends in waterfowl populations stopping over at Merrymeeting Bay as well as about the environmental changes thought to influence ducks. Interviewees generally agreed that there were far greater numbers of migrating ducks and geese prior to 1980 and that this abundance corresponded with much greater productivity of the emergent plant communities. Several hunters recollected Wild Rice flats that were too thick to walk through and flocks of ducks numbering in the tens of thousands. The hunters connected this luxuriant plant growth with fertilization by raw sewage coming down the two large rivers. The irony was striking. Hunters fondly recalled the prodigious numbers of ducks and geese along with the vibrant emergent plant communities and in the next sentence described floating mats of raw sewage and discolored water originating from chemicals discharged from numerous upriver paper and textile mills.

Our field and aerial photographic studies are consistent with these recollections. In field surveys undertaken with canoe, powerboat, and airplane, we observed no more than 3500 ducks on Merrymeeting Bay at any one time prior to the opening of the 2005 migratory bird hunting season. This estimate is consistent with the observations of hunters in the years since 2005, yet Spencer et al. (1980) estimated that Merrymeeting Bay commonly supported ≈40,000 foraging ducks prior to opening day of the duck hunting season, and just as many geese in the spring.

The aerial photography studies indicated an overall decrease in the cover of emergent vegetation between 1956 and 1981 as well as a decrease in the area of emergent plant communities dominated by Wild Rice from 1956 through 1998 (Fig. 2A). Comparison of recent Wild Rice densities with those quantified by Skip Spencer in 1956 suggest much greater densities of Wild Rice in the pure Wild Rice community type 50 years ago, but similar Wild Rice densities in the mixed community type between 1956 and 2003 (Fig. 2B). Although the overall area inhabited by emergent vegetation decreased between 1956 and 1981 by 318 ha, the total area of intertidal sand and mud flats increased by 225 ha (Lichter et al. 2006, Spencer 1966), indicating that space was available for plant colonization.

The history of change in SAV areal coverage shows a precipitous decline between 1956 and 1961 (Spencer 1966), followed by a shallower decline from 1961 to 1981, at which point SAV reached a low of 1.58% of the total area of Merrymeeting Bay. After 1981, SAV begins what may be an incipient recovery to 2.74% of the total area (Fig. 3).

Nutrient limitation of intertidal emergent plant communities

The results of our fertilization experiment in the intertidal plant communities indicated pronounced site differences primarily associated with differences in substrate texture. Averaging over the nitrogen and phosphorus fertilization treatments, the fine-grained substrate showed greater stem density ($P = 0.0001$) and final biomass ($P < 0.0001$) than the intermediate and coarse-grained substrates (Fig. 4). The analysis of the individual treatment effects of nitrogen and phosphorus amendments showed a clear positive effect of nitrogen addition on stem density and final biomass of wild rice, but no apparent effect of phosphorus addition (Fig. 5 and Table 1). A significant site × nitrogen-addition effect indicated that Wild Rice plants receiving additional nitrogen were relatively more productive at the fine-grained site than at the intermediate and sandy sites (Table 1).

Discussion

Our retrospective study suggests that both regional processes and local environmental change influenced the number of migrating ducks using the Merrymeeting Bay ecosystem over the past five decades. Today, the number of ducks

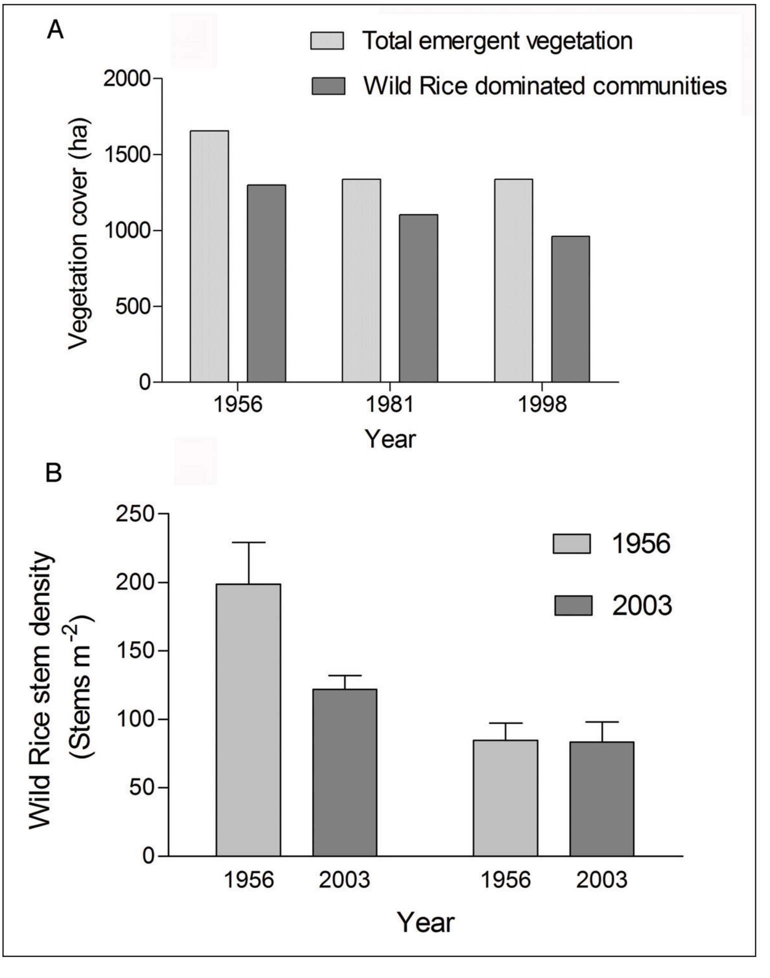

Figure 2. Total areal coverage of emergent vegetation in 1956, 1981, and 1998 based on aerial photography (A), and estimated Wild Rice stem density in pure Wild Rice stands and mixed emergent vegetation stands in 1956 and 2003 (B).

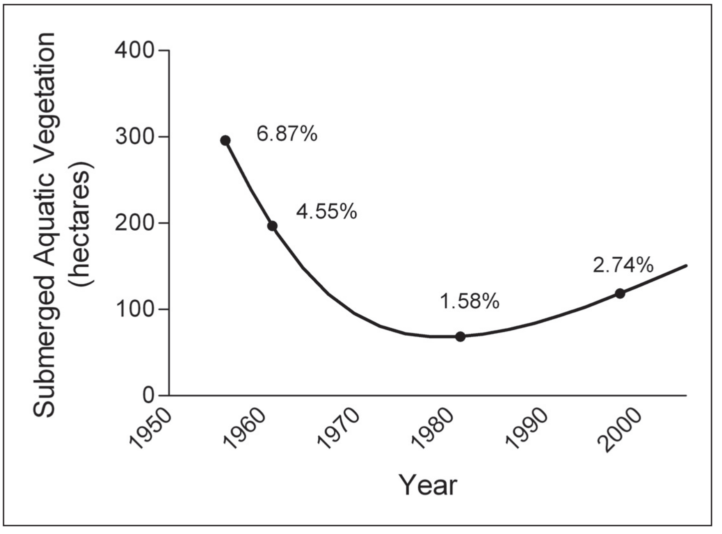

Figure 3. Change in area coverage of submerged aquatic vegetation based on aerial photography and field surveys for 1956 and 1961 (Spencer 1959, 1966) and on aerial photography alone for 1981 and 1998 (Burton 2007, Sewall 2000). Percentages of the total area of Merrymeeting Bay are given.

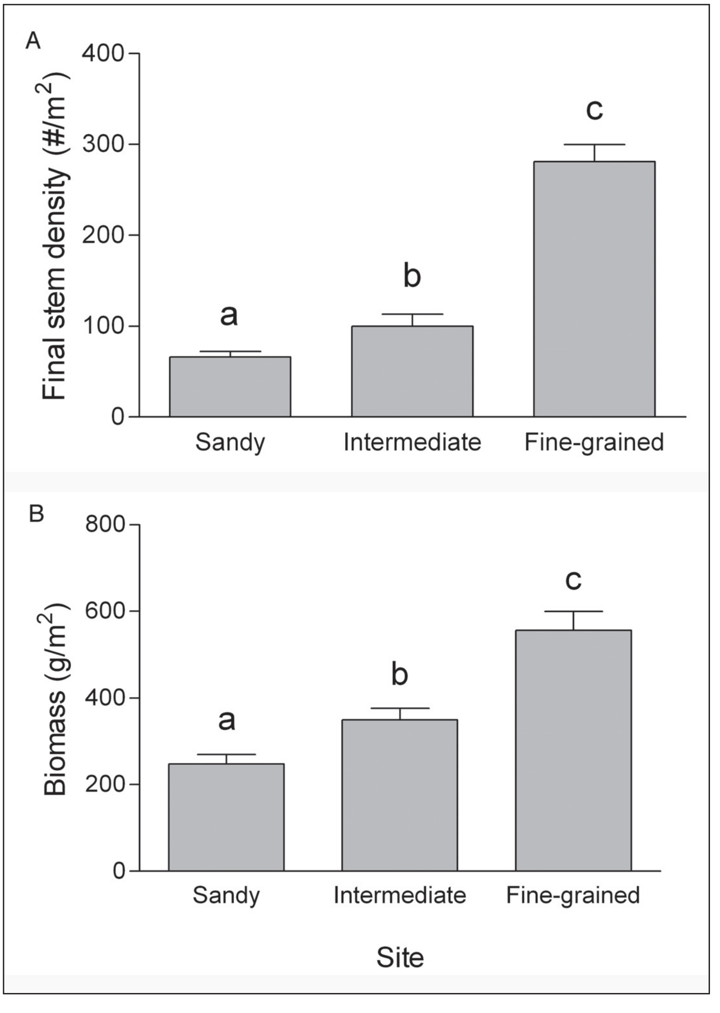

Figure 4. Wild Rice stem density (A) and final biomass (B) for each of three experimental sites averaged across N and P fertilization treatments.

foraging in Merrymeeting Bay during the fall migration has declined to one-tenth of the estimated tens of thousands of ducks commonly present in the decades prior to 1980. The loss of approximately one-half of regional duck populations migrating along the Atlantic flyway in response to degradation and loss of breeding and wintering habitat, hunting pressure, lead poisoning, and pesticide toxicity (Conroy et al. 2002; Hagar 1951; Longcore et al. 1982, 2000; Rusch et al. 1989) likely contributed to a reduced number of ducks observed in Merrymeeting Bay. However, declines in the spatial extent and productivity of the emergent intertidal plant communities and a collapse of SAV provided a less productive and diverse forage base. Prior to implementation of environmental regulation, fertilization of the emergent vegetation by raw water pollution probably attracted more ducks to Merrymeeting Bay than would otherwise have used the site.

Our nutrient-fertilization experiment suggests that nitrogen loading associated with the raw water pollution common in the decades before implementation of the Clean Water Act would have produced more plant biomass and greater stem densities of Wild Rice. This result is consistent with our comparison of Wild Rice stem densities between the years 1956 and 2003. Given that Wild Rice is an annual grass,

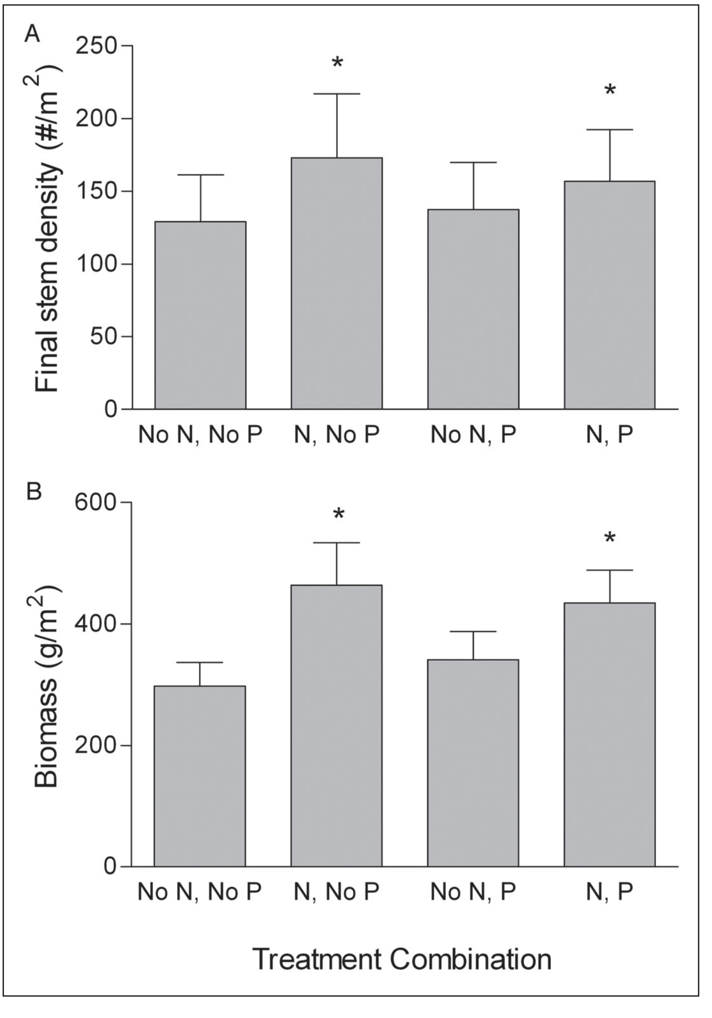

Figure 5. Effects of nutrient amendments on wild rice stem density (A) and final biomass (B). Accounting for variation in the initial density of Wild Rice seedlings among the replicated experimental plots, nitrogen addition produced higher stem densities and more plant biomass (Table 1).

seed production per unit area is likely to be strongly correlated with plant biomass and density. Although Wild Rice density can vary substantially from year-to-year because of differences in the conditions affecting seed production and seedling establishment, the similarity in stem density between comparison years in the mixed emergent plant community type suggests that seed production and dispersal were adequate in both 1956 and 2003 to fill the empty spaces within the mixed community type and produce a full crop of Wild Rice. Nutrient amendments associated with water pollution would allow more of the Wild Rice seedlings that establish reach full size and reproduce. When available, Wild Rice seed is consumed by many dabbling duck species (Martin et al. 1951). Formal studies of duck stomach contents, which included birds taken from Merrymeeting Bay, indicated that Wild Rice seed was the primary plant food consumed during the fall migration (Mendall 1949, Mendall and Spencer 1961, Spencer 1960).

In addition to nitrogen derived from wastewater, 6694 tons of sodium nitrate ($NaNO_3$) were dumped into the Androscoggin River between 1948 and 1960 as a chemical quick fix for hydrogen sulfide (H_2S) emanating out of the water when the river became anoxic in response to organic matter loading by pulp mills (Lawrance 1950, 1967). Pulp mills on the Androscoggin and Kennebec rivers at that time used a sulphite digestion process to break down wood pulp (Sutermeister 1941) and discharged the spent acidic liquor directly into the rivers (Lawrance 1967). Sulfur compounds were reduced to H_2S by bacteria under anaerobic conditions. The addition of $NaNO_3$ to the water allowed denitrifying bacteria to flourish, which could use the added nitrate (NO_3^-) as an electron acceptor and in the process brought oxygen concentrations above the threshold that the anaerobic sulfur-reducing bacteria could tolerate, thereby halting production

Table 1. ANOVA results for the nutrient fertilization experiment.

Variable	df	*F* value	*P*
Final Wild Rice density			
Initial seedling density	1	607.8	<0.0001
Site	2	11.0	0.0005
Nitrogen	1	28.6	<0.0001
Phosphorus	1	0.03	0.873
Site x nitrogen	2	13.9	0.0002
Site x phosphorus	2	1.1	0.348
Nitrogen x phosphorus	1	2.7	0.112
Site x nitrogen x phosphorus	2	2.0	0.16
Residuals	23		
Final biomass			
Initial seedling density	1	165.7	<0.0001
Site	2	6.2	0.007
Nitrogen	1	52.2	<0.0001
Phosphorus	1	0.6	0.463
Site x nitrogen	2	7.9	0.002
Site x phosphorus	2	0.5	0.599
Nitrogen x phosphorus	1	3.4	0.076
Site x nitrogen x phosphorus	2	3.2	0.059
Residuals	23		

of H_2S (Lawrance 1950). Although much of the added NO_3^- would have been denitrified and returned to the atmosphere, it is likely that the capacity of the river for denitrification was overwhelmed by the annual addition of hundreds of tons of $NaNO_3$ and consequently nitrogen loading was magnified downriver. Anthropogenic fertilization of the emergent plant communities is consistent with the recollection of veteran hunters, who were unanimous in claiming that the clearing waters contributed to the decline of the exceptional duck hunting common in the decades of the 1940s through the 1970s.

In addition to nitrogen fertilization by water pollution, siltation probably also enhanced the productivity of the emergent plant communities. Our fertilization experiment indicated that the fine-grained substrate produced more Wild Rice biomass and greater stem densities than did the intermediate-grained substrate, which in turn produced more biomass and greater stem density than the coarse-grained substrate. An enhanced stimulatory effect of nitrogen fertilizer was also observed at the fine-grained site relative to the intermediate and sandy sites. Presumably, much of the fine-grained sediment is derived from soil erosion associated with more than two centuries of logging and agriculture in the watershed. Coincident with widespread land clearance, sedimentation rates at the experimental site with fine-grained intertidal sediments increased from a low baseline rate in the early 18th century, followed by further acceleration of sedimentation during the 19th and 20th centuries as the human population grew (Köster et al. 2007). Although forest recovery began during the 1930s in much of southern Maine, high sedimentation rates associated with land use can continue for decades after forests have reestablished within a watershed (Francis and Foster 2001). Once again, human disturbance, in this case deforestation resulting in increased rates of sedimentation, most likely enhanced the productivity of the emergent plant communities in the middle decades of the 20th century leading to greater populations of foraging ducks during their autumn migration than would have otherwise used the site.

Much of the area of intertidal flats in Merrymeeting Bay contains fine-grained sediment. However, since the 1970s, at least one erosional event reduced the area of fine-grained sediments in Merrymeeting Bay and may have contributed to the overall decline in total cover of Wild Rice and the emergent plant communities over the last few decades. Veteran hunter Buster Prout stated that Wild Rice was much more productive at a few locations along the Kennebec channel before an unusually strong flood in the late 1980s carried away the silty surface sediments. Consistent with his recollection, melting snow and heavy rainfall in early April 1987 produced severe floods in several Maine rivers including the Androscoggin and Kennebec. A large sediment plume was observed with satellite sensors in the Gulf of Maine near the mouth of the Kennebec River; the plume was estimated to exceed 10^5 metric tons of fine-grained sediment (Stumpf and Goldschmidt 1992).

Whereas water pollution and enhanced rates of sedimentation probably increased the productivity of the intertidal, emergent plant communities, these human disturbances most likely precipitated the collapse of the subtidal, submerged aquatic vegetation. The survival and growth of aquatic plants are generally limited by light penetration of the water column (Harley and Findlay 1994, Havens 2003, Orth and Moore 1983, Scheffer et al. 1992). The raw sewage and tons of organic matter discharged upriver weekly by municipalities and industry caused severe turbidity in Merrymeeting Bay (Lichter et al. 2006, Reed and D'Andrea Co. 1975). Numerous historical accounts and a general consensus among the veteran hunters and other long-time residents of towns along the waterways suggest that the water was discolored and dark. Several hunters and other long-time residents of the area claim that you could not see two inches into the water.

The loss of SAV would have severely reduced the diversity and abundance of food items available to waterfowl. Aquatic plants play a pivotal role in lakes, rivers, and estuaries by supporting the benthic food web. Submerged vegetation and its epiphyton support a diverse and productive invertebrate community, which in turn supports a diverse and productive guild of consumers including waterfowl (Hargeby et al. 1994, Heck et al. 1995, Perry and Deller 1996, Strayer et al. 2003). In shallow lakes of moderate nutrient availability, regime shifts have been observed between a clear-water, SAV-dominated state, and a turbid-water, phytoplankton-dominated state (e.g., Blindow et al. 1993; Hargeby et al. 1994, 2004; McGowan et al. 2005; Scheffer et al. 1993). The clear-water state is sustained by feedbacks associated with aquatic vegetation. SAV promotes clear water by consuming nutrients and thereby leaving fewer to support phytoplankton growth (Scheffer et al. 1993), by trapping sediments (Barko et al. 1991, Benoy and Kalff 1999, Hamilton and Mitchell 1996), by providing refuge for zooplankton from plantivorous fish (Timms and Moss 1984), and by restricting the area of unvegetated sediments, thereby reducing bioturbation from benthivorous fish (Meijer et al. 1999, Perrow et al. 1997). Benthivorous fish such as *Cyprinus carpio* (Common Carp) stir up fine-textured sediments while foraging and dramatically increase the load of suspended solids (Cahn 1929, Cahoon 1953, Crowder and Painter 1991, Sidorkewicj et al. 1996, ten Winkel and Meulemans 1984, Zambrano et al. 2001).

In Merrymeeting Bay and its two large tributaries, SAV appears to have begun to recover. After declining rapidly during the 1950s through the 1970s (Spencer 1966) and reaching low abundance in 1981, the extent of aquatic plant beds rebounded somewhat between 1981 and 1998. However, the same cannot be said for the small tributaries emptying into Merrymeeting Bay. The Cathance, Muddy, Abagadasset, and Eastern rivers are each extremely turbid and support SAV only in their uppermost tidal reaches. Summer turbidity measurements indicate that the small rivers carry a much higher load of suspended inorganic sediments than do each of the two large rivers (Burton 2007). Tidal resuspension of fine-grained sediments probably contributes to this excessive turbidity in the small rivers; however, the Common Carp has also been implicated (Conners et al. 1982). Carp foraging is especially problematic in the small rivers because of the predominance of fine-grained sediments, whereas the subtidal portions of Merrymeeting Bay and the Androscoggin and Kennebec rivers are generally underlain by sandy substrates.

Conclusions

Historical information provides perspective for understanding this complex river-estuarine ecosystem, but also poses a paradox. Our interviews with veteran hunters and a retired waterfowl biologist as well as our reconstructed vegetation history and nutrient-fertilization experiment suggest that industrial and municipal water pollution of the mid-20th century coupled with two centuries of land-use change stimulated the productivity and spatial extent of the emergent plant communities. This enhancement of primary productivity would have made Merrymeeting Bay especially attractive to migrating ducks. Yet, anecdotal accounts of the preceding centuries indicate similar or even greater abundances of ducks and geese prior to industrialization within the watershed and the onset of eutrophication. Previous research reconstructing an environmental history of Merrymeeting Bay based on the sedimentary record indicates that the long-term, pre-industrial baseline condition was characterized by relatively clear, nutrient-poor waters (Köster et al. 2007). Therefore, the luxuriant productivity of the intertidal emergent plant communities observed during the mid-20th century ecosystem is not required to support large abundances of foraging waterfowl. It is likely that less productive emergent plant communities combined with more extensive submerged aquatic plant communities and a vibrant benthic food web provided the food resources needed to support enormous numbers of migrating waterfowl throughout the pre-industrial history of Merrymeeting Bay. Whereas numerous efforts have been made in the past to promote the establishment of Wild Rice for the benefit of migratory waterfowl (e.g., Spencer 1959), our results indicate that restoration and protection of SAV in Merrymeeting Bay might bring about the ecological recovery of this once vital ecosystem for the benefit of waterfowl and many other organisms.

Acknowledgments

This research was begun by students in an undergraduate seminar course at Bowdoin College during the fall of 2005 and was complemented with the undergraduate honors research of Julie Grinvalsky and Mark Burton. Veteran duck hunters Frank Burroughs, Ronnie Burrell, Buster Prout, John Edgecomb, Jim Brawn, Delbert Temple, Harold Nickerson, and Richard Nickerson along with retired DIFW duck biologist, Skip Spencer, provided invaluable information about the ecology and environmental history of Merrymeeting Bay, and taught us much about the value of empirical knowledge of ecosystems and of human interactions with ecosystems. The Friends of Merrymeeting Bay graciously provided the aerial photographs and GIS database compiled by the Sewall Company of Old Town, ME. Eileen Johnson provided GIS help and logistical support.

Literature Cited

Barko, J.W., D. Gunnison, and S.R. Carpenter. 1991. Sediment interactions with submersed macrophyte growth and community dynamics. Aquatic Botany 41:41–65.

Benoy, G.A., and J. Kalff. 1999. Sediment accumulation and Pb burdens in submerged macrophyte beds. Limnology and Oceanography 44:1081–1090.

Blindow, I., G. Andersson, A. Hargeby, and S. Johansson. 1993. Long-term pattern of alternative stable states in two shallow eutrophic lakes. Freshwater Biology 30:159–167.

Burton, M.E.H. 2007. Human disturbance and food-web structure in Merrymeeting Bay, mid-coast Maine. Honors Thesis. Biology Department, Bowdoin College, Brunswick, ME.

Cahn, A.R. 1929. The effect of carp on a small lake: The carp as dominant. Ecology 10:371–374.

Cahoon, W.G. 1953. Commercial carp removal at Lake Mattamuskeet, North Carolina. Journal of Wildlife Management 17:312–316.

Conners, J., A.C. Myers, and B. Timson. 1982. The turbidity problem in the Eastern River, Dresden Maine. Report for the Dresden Planning Board, Earth Surface Research, Inc. (Available by request from J. Lichter).

Conroy, M.J., M.W. Miller, and J.E. Hines. 2002. Identification and synthetic modeling of factors affecting American Black Duck populations. Wildlife Monographs Number 150, Supplement to the Journal of Wildlife Management 66.

Crowder, A.J., and D.S. Painter. 1991. Submerged macrophytes in Lake Ontario: Current knowledge, importance, threats to stability, and needed studies. Canadian Journal of Fisheries and Aquatic Science 48:1539–1545.

Fenster, M.S., D.M. FitzGerald, D.F. Belknap, B.A. Knisely, A. Gontz, and I.V. Buynevich. 2005. Controls on estuarine sediment dynamics in Merrymeeting Bay, Kennebec River estuary, Maine, USA. Pp. 173–194, *In* D.M. FitzGerald and J. Knight (Eds.). High Resolution Morphodynamics and Sedimentary Evolution of Estuaries. Springer, Dordrecht, The Netherlands.

Francis, D.R., and D.R. Foster. 2001. Response of small New England ponds to historic land use. The Holocene 11:301–312.

Hagar, J.A. 1951. New England waterfowl management: Black Duck program. Massachusetts Waterfowler 2:3–4.

Hamilton, D.P., and S.F. Mitchell. 1996. An empirical model for sediment resuspension in shallow lakes. Hydrobiologia 317:209–220.

Hargeby, A., G. Andersson, I. Blindow, and S. Johansson. 1994. Trophic web structure in a shallow eutrophic lake during a dominance shift from phytoplankton to submerged macrophytes. Hydrobiologia 279/280:83–90.

Hargeby, A., I. Blindow, and L-A. Hansson. 2004. Shifts between clear and turbid lakes in a shallow lake: Multi-causal stress from climate, nutrients, and biotic interactions. Arch. Hydrobiologia 161:433–454.

Harley, M.T., and S. Findlay. 1994. Photosynthesis-irradiance relationships for three species of submersed macrophytes in the tidal freshwater Hudson River. Estuaries 17:200–205.

Havens, K.E. 2003. Submerged aquatic vegetation correlations with depth and light-attenuating materials in a shallow subtropical lake. Hydrobiologia 493:173–186.

Heck, K.L., Jr., K.W. Able, C.T. Roman, and M.P. Fahey. 1995. Composition, abundance, biomass, and production of macrofauna in a New England estuary: Comparisons among Eelgrass meadows and other nursery habitats. Estuaries 18:379–389.

Kistner, D.A., and N.R. Pettigrew. 2001. A variable turbidity maximum in the Kennebec estuary, Maine. Estuaries 24:680–687.

Köster, D., J. Lichter, P.D. Lea, and A. Nurse. 2007. Historical eutrophication in a river-estuary complex in mid-coast Maine. Ecological Applications 17:765–778.

Lawrance, W.A. 1950. The addition of sodium nitrate to the Androscoggin River. Sewage and Industrial Wastes 22:820–832.

Lawrance, W.A. 1967. A twenty-five year review of Androscoggin River pollution control activities. A report to the Androscoggin River Technical Committee, Lewiston, ME.

Lichter, J., H. Caron, T.S. Pasakarnis, S. Rodgers, T.S. Squiers, Jr., and C.S. Todd. 2006. The ecological collapse and partial recovery of a freshwater tidal ecosystem in mid-coast Maine. Northeastern Naturalist 13:153–178.

Longcore, J.R., P.O. Corr, and H.E. Spencer, Jr. 1982. Lead-shot incidence in sediments and waterfowl gizzards from Merrymeeting Bay, Maine. Wildlife Society Bulletin 10:3–10.

Longcore, J.R., D.G. McAuley, D.A. Clugston, C.M. Bunck, J-F. Giroux, C. Ouellet, G. R. Parker, P. DuPuis, D.B. Stotts, and J.R. Goldsberry. 2000. Survival of American Black Ducks radiomarked in Quebec, Nova Scotia, and Vermont. Journal of Wildlife Management 64:238–252.

Maine Department of Environmental Protection (MDEP). 1979. The Kennebec River, 1978 water quality: A historic perspective. Augusta, ME.

Martin, A.C., H.S. Zim, and A.L. Nelson. 1951. American Wildlife and Plants: A Guide to Wildlife Food Habits. McGraw-Hill Book Company, Inc., New York, NY.

McGowan, S., P.Leavitt, R.I. Hall, N.J. Anderson, E. Jeppesen, and B.V. Odgaard. 2005. Controls of algal abundance and community composition during ecosystem state change. Ecology 86:2200–2211.

McKeen, J. 1853. Some accounts of the early settlements at Sagadahock and on the Androscoggin River. Article V. Collections of the Maine Historical Society, Vol. III. Portland, ME.

Meijer, M.-L., I. DeBoois, M. Scheffer, R. Portielje, and H. Hosper. 1999. Biomanipulation in shallow lakes in the Netherlands: An evaluation of 18 case studies. Hydrobiologia 408:13–30.

Mendall, H.L. 1949. Food habits in relation to Black Duck management in Maine. Journal of Wildlife Management 13:64–101.

Mendall, H.L., and H.E. Spencer, Jr. 1961. Waterfowl harvest studies in Maine (1948–1957). Maine Department of Inland Fisheries and Game, Game Diversion Bulletin No. 7. Augusta, ME.

Noble, F.T. 1905. The ducks of Merrymeeting Bay in the season of 1905. The Journal of the Maine Ornithological Society 7:65–70.

Orth, R.J., and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science 222:51–53.

Penhallow, S. 1726. The History of the Wars of New England with the Eastern Indians. Reprinted from the Boston Edition of 1726 by O.H. Harpel. 1859.

Perrow, M.R., M.-L. Meijer, P. Dawidowicz, and H. Coops. 1997. Biomanipulation in the shallow lakes: State of the art. Hydrobiologia 342:355–365.

Perry, M.C., and A.S. Deller. 1996. Review of factors affecting the distribution and abundance of waterfowl in shallow-water habitats of Chesapeake Bay. Estuaries 19:272–278.

Reed and D'Andrea Company. 1975. Merrymeeting Bay: A guide to conservation of a unique resource. Report prepared for the Maine Department of Conservation, South Gardiner, ME.

Rusch, D.H., C.D. Ankney, H. Boyd, J.R. Longcore, F. Montabano III, J.K. Ringelman, and V.D. Stotts. 1989. Population ecology and harvest of the American Black Duck: A review. Wildlife Society Bulletin 17:379–406.

Scheffer, M., M.R. de Redelijkheid, and F. Noppert. 1992. Distribution and dynamics of submerged vegetation in a chain of shallow eutrophic lakes. Aquatic Botany 42:199–216.

Scheffer, M., S.H. Hosper, M-L Meijer, B. Moss, and E. Jeppesen. 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution 8:275–279.

Sewall Company. 2000. Aquatic and upland habitat assessment of Merrymeeting Bay. Assessment report prepared for the Friends of Merrymeeting Bay. James W. Sewall Company, Old Town, ME.

Sidorkewicj, N.S., A.C. Lopez-Carzola, and O.A. Fernández. 1996. The interaction between *Cyprinus carpio* L. and *Potamogeton pectinatus* L. under aquarium conditions. Hydrobiologia 340:271–275.

Spencer, H.E., Jr. 1957. Merrymeeting Bay: Maine's waterfowl haven. Game Division Leaflet Series Vol. 1, No. 1., Maine Department of Inland Fisheries and Game, Augusta, ME.

Spencer, H.E., Jr. 1959. Merrymeeting Bay investigations. Project Number W-37-R-7. Maine Department of Inland Fisheries and Wildlife, Augusta, ME.

Spencer, H.E., Jr. 1960. Merrymeeting Bay investigations. Project Number W-37-R-9. Maine Department of Inland Fisheries and Wildlife, Augusta, ME.

Spencer, H.E., Jr. 1966. Merrymeeting Bay investigations. Project Number W-37-R-14. Maine Department of Inland Fisheries and Wildlife, Augusta, ME.

Spencer, H.E., Jr., J. Parsons, and K.J. Reinecke. 1980. Waterfowl. *In* S.I. Fefer and P.A. Schettig (Eds.). An Ecological Characterization of Coastal Maine (North and East of Cape Elizabeth). Interior Department, US Fish and Wildlife Service, Northeast Region, Newton Corners, MA.

Strayer, D.L., C. Lutz, H.M. Malcom, K. Munger, and W.H. Shaw. 2003. Invertebrate communities associated with a native (*Vallisneria americana*) and an alien (*Trapa natans*) macrophyte in a large river. Freshwater Biology 48:1938–1949.

Stumpf, R.P., and P.M. Goldschmidt. 1992. Remote sensing of suspended sediment discharge into the western Gulf of Maine during the April 1987 100-year flood. Journal of Coastal Research 8:218–225.

Sutermeister, E. 1941. Chemistry of Pulp and Paper Making. John Wiley and Sons, Inc. New York, NY.

ten Winkel, E.H., and J.T. Meulemans. 1984. Effects of fish upon submerged vegetation. Hydrobiological Bulletin 18:157–158.

Timms, R.M., and B. Moss. 1984. Prevention of growth of potentially dense phytoplankton populations by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. Limnology and Oceanography 29:472–486.

Walker, C.L. 1931. Survey and report of river and stream conditions in the State of Maine 1930. Biennial Report to the Govenor, Augusta, ME.

Walsh, H.M. 1971. The Outlaw Gunner. Tidewater Publishers. Cambridge, MD.

Wheeler, G.A., and H.W. Wheeler. 1878. History of Brunswick, Topsham, and Harpswell, Maine. Alfred Mudge and Son, Printers. Boston, MA.

Wilkens, K.A., M.C. Otto, G. S. Zimmerman, E.D. Silverman, and M.D. Koneff. 2007. Trends in duck breeding populations, 1955–2007. Administrative report, July 11, 2007, US Fish and Wildlife Service, Division of Migratory Bird Management, Laurel, MD.

Wong, M.W., and D.W. Townsend. 1999. Phytoplankton and hydrography of the Kennebec estuary, Maine, USA. Marine Ecology Progress Series 178:133–144.

Zambrano, L., M. Scheffer, and M. Martinez-Ramos. 2001. Catastrophic response of lakes to benthivorous fish introduction. Oikos 94:344–350.