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Reconstructing New England Salt Marsh Losses Using Historical Maps

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ABSTRACT: Analyses of habitat loss are often restricted to the past 75 years by the relative youth of aerial photography and remote sensing technologies. Although photographic techniques are highly accurate, they are unable to provide measurements of habitat loss prior to the 1950s. In this study, historical maps from the late 1700s and early 1800s covering portions of Rhode Island, Massachusetts, New Hampshire, and Maine were used to approximate naturally occurring salt marsh cover in New England. Historical data was compared to current salt marsh coverage available in public geographic information system (GIS) data sets. The average loss in New England is estimated at 37% using this technique. Rhode Island has lost the largest proportion of salt marshes by state, a staggering 53% loss since 1832. Massachusetts has also experienced large losses, amounting to a 41% loss of salt marsh since 1777. The Boston area alone has lost 81% of its salt marshes. Salt marsh loss was highly correlated with urban growth. Restoration and preservation efforts have resulted in the retention of salt marsh in less populated areas of New England. Although historical maps are difficult to verify, they represent an extremely valuable and underused data repository. Using historical maps to trace land use practices is an effective way to overcome the short-term nature of many ecological studies. This technique could be applied to other habitats and other regions, wherever accurate historical maps are available. Analysis of historic conditions of habitats can help conservation managers determine appropriate goals for restoration and management.

Introduction

Habitat destruction has been recognized as a universal threat to biodiversity (Soule 1991). Analyzing trends of habitat loss on a regional scale has become more feasible since the advent of remote sensing and geographic information system (GIS) technologies, and rates of habitat loss have been tabulated more frequently in the last few decades. Habitat loss is not a new phenomenon. Recent studies have revealed that humans have been significantly altering the landscape since prehistoric times (Flenley et al. 1991; Willis et al. 2004), and in New England, that effect has dramatically reduced salt marsh coverage.

Limited data availability has curtailed efforts to document earlier periods of salt marsh loss. Aerial photography dates back less than 75 yr for most areas, and, consequently, the last 75 yr are the only years represented in most wetlands trends analyses. This paper, using historical maps of portions of Rhode Island (RI), Massachusetts (MA), New Hampshire (NH), and Maine (ME), extends beyond the realm of aerial photography to examine the last 200 yr of human effects on New England salt marshes.

Coastal habitats in the densely populated region of New England have long experienced particularly deleterious anthropogenic effects. New England's population has increased nearly continuously in the last 200 yr. Increased population densities and suburban sprawl resulted in the conversion of substantial areas of natural land to urban and industrial use. Expansion of the coastal cities of New York, New York (NY), New Haven, Connecticut (CT), Providence, RI, and Boston, MA, has formed a nearly continuous corridor of developed land.

Although humans have discovered many benefits of converting salt marshes, there are countless benefits of maintaining these habitats (Costanza et al. 1997). Salt marshes buffer inland areas from erosion and flooding during the severe storms that are characteristic of the region. They are home to filter feeding organisms that cleanse polluted waters and commercially viable species that thousands of people in the northeastern United States depend upon for their livelihood. Salt marshes, with their dense intertidal vegetation, serve as sheltered nurseries for many species of young fish, lobster, and shrimp (Turner 1977; Boesch and Turner 1984; Bertness 1999). Salt marshes also are among the most productive ecosystems on earth, with primary productivity rates in some areas comparable to coral reefs and tropical forests (Reidenbaugh 1983; Mitsch and Gosselink 1993; Silliman and Bortolus 2003).

All evidence suggests that salt marsh loss in New England has been severe. Salt marshes once covered much of the coastal northeastern U.S. (Nixon 1982; Stilgoe 1994). Anecdotal estimates place total loss at

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around 50% (Agardy 1997). Although numerous estimates have documented the rate of salt marsh loss over the last 50 or 100 yr, an appreciation of salt marsh loss since European colonization has proved elusive.

Human Exploitation of New England Salt Marshes

New England salt marshes have a history of exploitation dating back to the arrival of Europeans in New England. Dutch and English settlers took to the salt marshes as familiar landscapes and founded towns with access to marshes in mind (Russell 1976).

Salt marsh plants were central to early colonial life. Salt hay, *Spartina patens*, was farmed for animal bedding and used as animal feed with high marsh black grass, *Juncus gerardi*, mixed in for better nutrition (Nixon 1982). Thatch grass, *Spartina alterniflora*, was used for roofing houses (Russell 1976). So valuable were salt marshes in the 1700s that there are accounts of farmers attempting to convert land into salt marsh by extending creeks, although little marsh was probably created in this way (Nixon 1982).

In the mid 1800s, salt hay farming fell out of favor as freshwater hay species became more commonly used for animal feed. Most agriculture moved westward following the promise of ample and inexpensive fertile land in the Mississippi River basin (Pavelis 1987). The U. S. Federal Swampland Acts of 1849, 1850, and 1860 passed authority over large areas of wetlands to the states, which, in turn, sold the land to farmers for revenue (Gosselink and Baumann 1980). Reclamation of salt marshes became widespread, as farmers were encouraged to drain marshland by ditching or installing of tidal gates in order to cultivate freshwater crops (Stilgoe 1994).

Upon the discovery in 1897 that mosquitoes are disease vectors, attempts were made at mosquito eradication. Ditching of marshes for mosquito control became common during the depression, when the Civilian Conservation Corps and the Works Progress Administration ditched over 95% of the northeastern marshlands, primarily to offer employment opportunities (Buchsbaum 2001). Immigration in the late 1800s and early 1900s necessitated housing and construction projects of a scale that had not been previously known in the cities of New England. Over 2,000 ha of salt marsh and mudflat in the Boston area were filled in for various industrial and urban growth projects, most of which took place between 1830 and 1930 (Seasholes 2003).

Maltreatment of New England salt marshes continued until the 1970s, at which point the U.S. general public and federal government began to recognize the ecological services that salt marshes provide as marine nurseries, shorebird habitat, and coastal stabilizers. The Federal Water Pollution Control Act, later called the Clean Water Act, was enacted in 1972. Under Section 404 of the Clean Water Act, salt marsh, both public and private, became protected from dredging or filling except by permit issued by the Corps of Army Engineers. In 1988, President George H. W. Bush set a national goal of "no net loss" of wetlands and began more rigorous enforcement of Section 404 (USGPO 1990). Losses of wetlands nationally have since slowed (Heimlich et al. 1998). New England salt marshes are still plagued by a number of problems. Nutrient runoff, *Phragmites* invasion, overfishing, and sea level rise continue to threaten remaining salt marshes (Donnelly and Bertness 2001; Bertness et al. 2004).

Wetland Loss Estimates

Estimates of wetland loss, which incorporate salt marsh loss, have been used to assess the risk to different types or locations of wetlands, to pinpoint the causes of loss, and to develop effective prevention methods. Surveys of wetlands in the U.S. have been commissioned by numerous federal agencies, including the National Resources Inventory, Bureau of Agricultural Economics, Soil Conservation Service (all within the U.S. Department of Agriculture), and the National Wetland Inventory (within the U.S. Fish and Wildlife Service), each agency with its own survey methods. Since 2000, federally commissioned wetland inventories have been handled exclusively by the National Resources Inventory (National Wetland Newsletter 1998).

At least three major drawbacks have limited the utility of past wetland loss estimates in interpreting long-term trends. Definitions of wetlands have shifted over the years, making a consistent analysis over time difficult. In some studies, swamps refers to salt marshes (Shaler 1886), yet in others swamps refers exclusively to freshwater marshes (Wright 1907). The treatment of subtidal vegetation differs between surveys as well (Gosselink and Baumann 1980). The creation of a standardized classification system by Cowardin et al. (1979) has fixed this problem in current data sets (Tiner 1996).

National long-term loss estimates often group all wetland types together (e.g., Dahl 1990; Heimlich et al. 1998). These estimates are useful in correlating general wetland loss with national economic and cultural trends, but many details are lost in this type of analysis, such as the particular risk to coastal wetlands.

Estimates of loss require baseline data, which ideally would predate human effects. Percentages of loss using baseline data from the 1950s or later disregard any losses that occurred earlier, which, considering the high level of historic human exploitation of salt marshes in New England, is likely to be substantial.

Before the U.S. Geological Survey was formed in 1879, the quality and availability of historic data sets was unreliable. One exception is the early maps published by the U.S. Coast Survey, founded in 1834. Accurate maps containing land use data from before then are rare. Only starting in 1879 have scientists had access to consistent, highly detailed, and accurate maps.

Most existing wetland loss estimates are either anecdotal (Teal and Teal 1969; Watzin 1992; Agardy 1997) or cover only the past 50 yr (Frayer et al. 1983; Heimlich and Melanson 1995; Dahl 2000). Older baseline data of wetlands in the U.S. comes from U.S. Department of Agriculture surveys of uncultivable land. While comprehensive, the Department of Agriculture's baseline data are imprecise; the 1906 survey was done piecemeal, with each county providing its own data, and the 1922 survey of wetlands was based on soil surveys and drainage reports, which are capable of identifying only about 85% of wetlands (Heimlich et al. 1998).

Only three prior studies have attempted to capture wetland loss since European settlement in North America by using baseline historical data from before 1900. Dahl (1990) used a variety of state park documents and soil surveys to estimate wetland loss from the 1780s to 1980s. He did not separate wetlands by type, limiting the utility of the data. In a review of wetland inventories, Gosselink and Baumann (1980) used data collected by Shaler (1886) and various government surveys to reconstruct salt marsh loss in New England and New York from 1886 to 1976. Gosselink and Baumann found that the period of most rapid salt marsh loss was between 1922 and 1954, with losses slowing in the second half of the 20th century. Marsh loss rates (1954–1974) were closely correlated with population densities of coastal counties. While thorough, that research still ignored a long period of human effects.

The Connecticut Department of Environmental Protection (CTDEP) did a study comparing CT salt marsh coverage in the Coast and Geodetic Map Series from the 1880s to 1970s using methods similar to this study (Dreyer and Niering 1995). Like Gosselink and Baumann (1980), the CTDEP study had no data from before the 1880s, a period of intense population growth and urban development in New England.

This study attempts to set a baseline earlier in time using salt marsh coverage data from historical maps to provide a more comprehensive picture of coastal marsh conversion in New England over the years since European settlement. We expected to find that salt marsh loss in New England over the last few centuries is slightly higher than the 30% loss of salt marsh found in CT by the CTDEP from the 1880s–1970s (Dreyer and Niering 1995). Shared geography and common history would likely have resulted in similar loss rates in other New England marshes but the longer time period examined by this study would account for wetland losses that occurred even earlier in history than 1880.

Methods

We calculated an estimate of salt marsh and urban land cover change in New England by comparing historical maps with current land use data. For portions of New England where both historical and current data were available, we selected historical maps and current GIS data, which delineated marshes, and we measured salt marsh and urban coverage areas within each map. These areas were used to develop an estimate of salt marsh loss, from which total salt marsh loss was extrapolated.

The Cowardin classification of "estuarine emergent" was used to identify salt marshes in current GIS data (Cowardin 1979). Fresh and brackish tidal marshes are included within this classification. Fresh, brackish, and salt marshes were undifferentiated on historical maps and, on most historical maps, were indicated by a mottled pattern defined as marsh on the legend. Areas were classified as urban if they had four or more residences per acre. Commercial and industrial areas were also included as urban areas.

Percent change in salt marsh and urban area was calculated as follows, where current and historical areas refer to land use areas, and a negative percent implies a loss:

$$\text{Percent change} = \frac{(\text{current area} - \text{historical area}) \times 100}{\text{historical area}}$$

We were able to compare change in salt marsh and urban areas over approximately a 200-yr time interval for portions of the coastal states of RI, MA, NH, and ME (Fig. 1). The actual area of salt marsh lost by each state was back-calculated using the percent change and current area of salt marsh in the entire state (from National Wetlands Inventory [NWI] and MassGIS Land Use data layers, see Table 1), using the following equation, wherein the first term represents the calculated historical area of salt marsh in the entire state:

$$\text{Area lost} = \frac{\text{current statewide area}}{(1 + \text{percent change})} - \text{current statewide area}$$

To find adequate historical maps, we combed the archives of the John Carter Brown Library at Brown

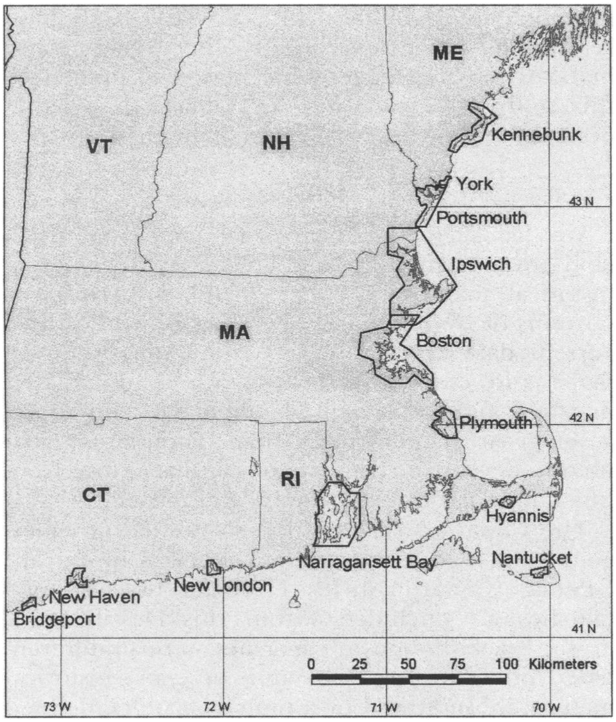

Fig. 1. Map areas used to estimate land use changes in New England (41–44°N, 68–72°W). Map areas are oddly shaped because most charts detailed only the coastal land area. Overlaps in the York and Portsmouth map areas and Boston and Ipswich map areas were accounted for in the percent change calculations.

University, the Sterling Memorial Library at Yale University, and the Rhode Island Historical Society in a search for the earliest maps containing accurate delineation of salt marshes. We also searched the collections of the U.S. Library of Congress, U.S. Naval Archives, and U.S. Office of Coast Survey for relevant material. Maps were included only if they were constructed by trigonometric survey, depicted land use types within distinct borders, and had accurately represented geographic formations. Coastline accuracy was used as an indicator of accurate surveying practices that would extend to land use data as well. Loss estimates by state were calculated using only maps that covered a regional area of at least 7,500 ha, to decrease sampling bias by maps that depicted only developed or undeveloped areas. Historical maps covering an area smaller than 7,500 ha were used in the development of a regression model to examine the relationship between salt marsh loss and urban development.

The scope of this study was limited to RI, MA, NH, and southern ME. No adequate regional historical maps of CT could be found, and the NWI, where most of the present day data on salt marsh coverage was obtained, has not yet been completed for the CT coastline. CT was excluded in the development of our salt marsh loss statistic, but smaller maps from areas of the CT coast where the NWI data is complete were included in development of the regression model. Salt marshes in NY and New Jersey are often grouped with other Northern Atlantic salt marshes, but were excluded in this study. Consequently, New England averages in this paper are based on six large maps of portions of RI, MA, NH, and ME (see Table 2 for map information). The areas covered by the historic maps used in this study are shown in Fig. 1.

All maps from the 1700s came from the Atlantic Neptune, an atlas of the east coast of the U.S. and

TABLE 1. Historical maps with salt marsh coverage used in this study. An asterisk after the map title denotes use in calculating average salt marsh loss estimate for New England. All maps were used in the development of the regression model.

Map title	Scale	Date of publication	Surveyor	Source
The Atlantic Neptune: Ipswich, MA*	1:50,000	1777	DesBarres, J. F. W.	John Carter Brown Library, Brown University
The Atlantic Neptune: Boston Harbor, MA*	1:50,000	1777	DesBarres, J. F. W.	John Carter Brown Library, Brown University
The Atlantic Neptune: Plymouth, MA*	1:25,000	1777	DesBarres, J. F. W.	John Carter Brown Library, Brown University
The Harbor of Hyannis	1:30,000	1850	Bache, A. D.	NOAA Office of Coast Survey
Nantucket Harbor	1:20,000	1848	Bache, A. D.	NOAA Office of Coast Survey
The Atlantic Neptune: Portsmith, NH*	1:25,000	1779	DesBarres, J. F. W.	Sterling Memorial Library, Yale University
A Chart of Narragansett Bay*	1:24,000	1832	Wadsworth, Capt. M. S.	Rhode Island Historical Society Library
Coast of Maine in the Vicinity of Kenneybunk Port*	Unavailable	1851	Unknown	NOAA Office of Coast Survey
York River Harbor, Maine	1:20,000	1854	Bache, A. D.	NOAA Office of Coast Survey
Harbors of Blackport Rock and Bridgeport	1:20,000	1848	Hassler, F. R.	NOAA Office of Coast Survey
New Haven Harbor	1:30,000	1846	Hassler, F. R.	NOAA Office of Coast Survey
The Harbor of New London	1:20,000	1846	Hassler, F. R.	NOAA Office of Coast Survey

TABLE 2. GIS data layers used in this study. Source acronyms are GRANIT: Geographically Referenced Analysis and Information Transfer, Complex Research Center, University of New Hampshire; MAGIC: Map and Geographic Information Center, University of Connecticut; MassGIS: Office of Geographic and Environmental Information, Commonwealth of Massachusetts Executive Office of Environmental Affairs; MEGIS: Maine Office of Geographic Information Systems, State of Maine; NWI: National Wetlands Inventory, U.S. Fish and Wildlife Service; RIGIS: Rhode Island Geographic Information Systems, University of Rhode Island.

State	Data layer title	Used to classify	Scale	Date of data collection	Source
Connecticut	Land use	Salt marsh	1:24,000	1990	MAGIC
	Land use	Urban	1:24,000	1990	MAGIC
	State boundary	State boundary	1:24,000	1995	MAGIC
Rhode Island	Statewide wetlands	Salt marsh	1:24,000	1988	RIGIS
	Land use	Urban	1:24,000	1995	RIGIS
	State of Rhode Island	State boundary	1:24,000	1976–1983	RIGIS
Massachusetts	Land use	Salt marsh	1:25,000	1999	MassGIS
	Land use	Urban	1:25,000	1999	MassGIS
	Community boundaries	State boundary	1:25,000	2002	MassGIS
New Hampshire	National wetlands inventory	Salt marsh	1:24,000	1986	NWI
	Land use	Urban	1:12,000	1998	GRANIT
	New Hampshire political boundaries	State boundary	1:24,000	1986	GRANIT
Maine	National wetlands inventory data	Salt marsh	1:24,000	1983–1986	MEGIS
	Digital raster graphics (DRGCLIP)	Urban	1:24,000	1995	MEGIS
	Maine townships (METWP24)	State boundary	1:24,000	1971	MEGIS

Canada surveyed and published by J. F. W. DesBarres (Henry Stevens, Son and Stiles 1937). DesBarres was among the first to use triangulation for surveying coastlines; the results are maps that are uncommonly accurate for their time (Evans 1969). Surveying for the atlas was done between 1763 and 1773. The other historical maps used were published between 1832 and 1854 by the U.S. Coast Survey, with the exception of the map of Narragansett Bay, RI, published by Capt. M. S. Wadsworth in 1832. Throughout the text, all maps published between 1777 and 1854, are grouped as historical, the intent being to establish an early baseline to which present day data can be compared.

To analyze the Atlantic Neptune and Wadsworth historical maps using GIS, we digitally photographed the historic maps and georeferenced them using Blue Marble Graphics' Geographic Transformer (version 4.2). This software was used to project the maps into a NAD83 Massachusetts State Plane projection, in which form they could be compared to current data sets. This procedure effectively reduced any error or skew within the historical maps to the level of state boundary GIS data (Table 1). Coastlines were intentionally lined up during georeferencing, assuming no change along the coast due to sea level rise or erosion (major anthropogenic changes to the shoreline were avoided and only natural features were matched). Although the rubber-sheeting transformation technique is imperfect (see Petry and Somodevilla 2000 for discussion), it was the only option for transforming unprojected historical maps in order to compare them with projected GIS data layers (most of the historical maps were made before standardized map projections were being used). The root-mean-square (RMS) error associated with the transformation models for these five maps was between 160 and 440 m, with a mean value of 245 m. RMS error is a measure of the distance the historical map points were refitted to match the current map projection. Although these RMS errors are high by current standards, this error was effectively removed from the analysis during the transformation process. Maps published by the U.S. Coast Survey were obtained from National Oceanic and Atmospheric Administration's Office of Coast Survey archives in a digital, georeferenced form and needed no transformation.

The transformation process did not line up the historical and present day maps seamlessly. In some places, land in the historical map covered sea in the present day map and vice versa, despite the assumption of no coastline change. For this reason, only changes in area were analyzed. Conversion of tidal marshes to different land use types could not be addressed.

Land coverage data was analyzed in ESRI's mapping program Arcview 3.3. Salt marsh and urban land use features of historical maps were hand-outlined in GIS and converted into digital shapefiles. Hand-outlined historical salt marsh features excluded tidal creeks, because water bodies are also excluded in current GIS wetland data sets. All current wetland and urban data used were available through public GIS catalogs (NH GRANIT,

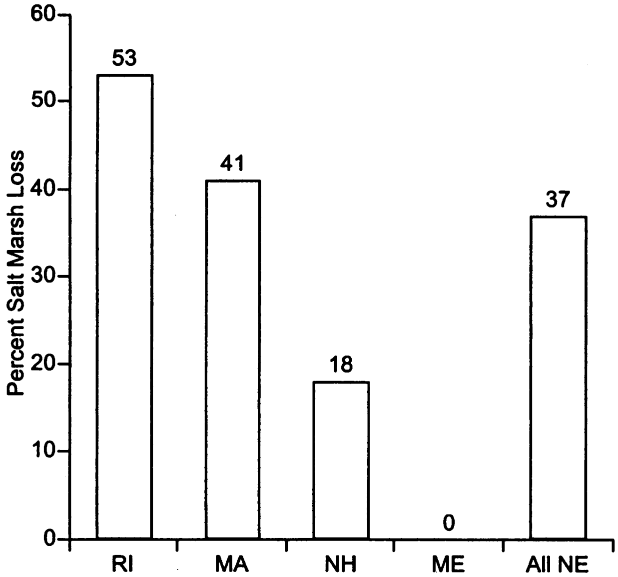

Fig. 2. Percentage of salt marsh lost in Rhode Island (RI), Massachusetts (MA), New Hampshire (NH), and Maine (ME) over the last 200 yr. At right, a weighted average of states losses are used to estimate salt marsh loss over all of New England (NE). Numbers above bars are the percentage values.

MAGIC, MassGIS, MEGIS, NWI, and RIGIS, Table 1). Current GIS data layers were clipped to the areas detailed in the historic maps to make the data sets comparable.

When the historical and current data sets were both in digital forms, they were divided by state and by watershed for comparisons between culturally and geographically relevant land areas. Classification scheme of watersheds varied state to state. In all states, major basin or the equivalent was used.

A polynomial regression model was used to relate the area of urban growth to the area of salt marsh loss, with a square root power transformation used to normalize the urban coverage data. The 12 map areas (6 regional and 6 smaller maps, Fig. 1) covered portions of 22 different watersheds (n = 22 for the regression model).

Results

Based on the sampled portions of New England examined in this study, 37% of the original salt marsh of New England has been lost. RI has lost the highest percentage of salt marsh, a 53% loss (Fig. 2). MA has lost the second largest percentage, 41%. Most of the loss in MA occurred around Boston; the greater Boston area has lost 81% of its marshes since 1777 (Fig. 3). NH has lost a lower proportion of salt marsh, 18%, and ME has lost only 1 ha of salt marsh or <1% since 1851.

It should be noted that in the Kennebunk, ME, map area, 57% of the remaining salt marsh is protected within the Rachel Carson National Wildlife Refuge. Only a small proportion of Maine's coast was adequately detailed by historic maps, and the inclusion of the refuge in the sample may have made the state's average percentage of loss lower than it would have been if data from the entire coastline had been considered.

From the percent loss estimate, we calculated area lost by each state. According to this calculation, MA has lost the largest area of salt marsh at 13,352 ha. RI has lost 1,831 ha. NH has lost 500 ha, and ME

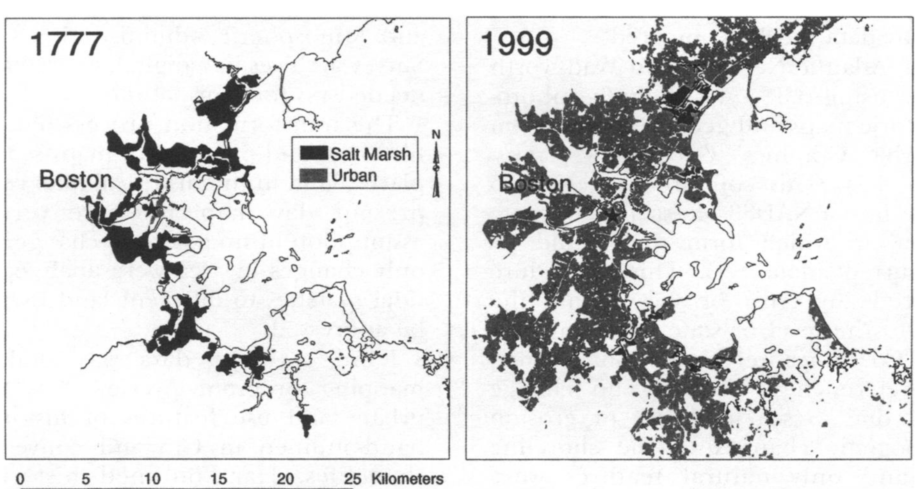

Fig. 3. Salt marsh and urban land cover in Greater Boston (42°N, 71°W) in 1777 and 1999. The coastlines in both maps are the 1999 coastline and include some land built on fill that did not exist in 1777 (identifiable from the unnaturally shaped coastline made up almost entirely of wharves surrounding the star denoting Boston).

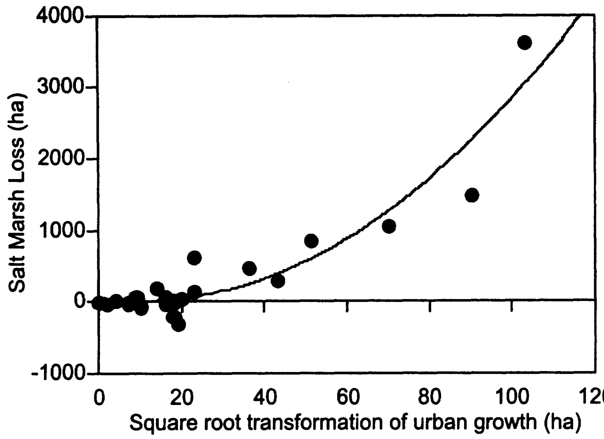

Fig. 4. The percentage of salt marsh loss increased significantly with the extent of urbanization ($p < 0.001$, $R^2 = 0.8889$, $f(x) = 0.356x^2 - 7.847x + 62.328$). Each point represents growth of urban area and loss of salt marsh area estimated within one watershed over a period of about 200 yr. Area of urban growth was square root normalized to increase accuracy of the regression, and 2 ha was added to every urban growth value to allow square root transformation of one negative value ($f(x) = \sqrt{(y + 2)}$).

has lost 569 ha. For reference, according to NWI data, there currently remains 30,679 ha of coastal marsh in those four states combined.

There was a relationship between area of salt marsh lost and area of urban land gained. Salt marsh loss was significantly correlated with urban growth (Fig. 4, $R^2 = 0.8889$, $p < 0.001$). At low levels of urban growth, little to no salt marsh was lost, and 7 watersheds of low urban growth (<500 ha) showed a slight increase in salt marsh coverage over the last two centuries.

Discussion

Salt Marsh Conversion

As expected, the greater amount of time accounted for in this estimate resulted in the finding of a greater amount of salt marsh loss than past short-term estimates, in some cases by an order of magnitude. Frayer et al. (1983) estimated an 8% loss of estuarine emergent wetlands (salt marsh and mangroves, as classified by the Cowardin system) in the U.S. between 1954 and 1974. Dahl (2000) found a less than 1% loss of estuarine emergent wetlands in the U.S. between 1986 and 1997. These short-term estimates are useful in analyzing broad trends of wetland loss, but the absolute losses of estuarine emergent wetland in New England states has been much greater over the long term.

Our estimate of 37% loss of New England's salt marshes over the last 200 yr is consistent with CTDEP's finding of a 30% loss of salt marshes in CT from 1880 to 1970. Gosselink and Baumann (1980) found a 54% loss of coastal marsh in New England and Atlantic NY from 1886 to 1976. Our estimate is lower, despite the longer time interval, perhaps due to the exclusion of NY, where explosive urban growth has no doubt resulted in considerable marsh losses.

The direct cause of loss is difficult to ascertain. Sea level rise, hydrologic alterations (by damming, ditching, or filling), and development of urban or agricultural land are all common causes of salt marsh conversion (Roman et al. 1984; Dahl 1990) and are probably all, in part, responsible for the losses in New England. In the time span covered by this study, multiple conversions may have taken place. Many northeastern salt marshes were converted to cropland in the 1800s and later converted to urban land. With only two snapshots in time of land use, we could incorrectly conclude that these marshes were converted directly to urban land.

There is evidence that urban growth was a direct cause of salt marsh loss. Salt marshes were valued as sources of natural resources, such as for salt hay, even without conversion to agricultural land. In the mid 1800s when conversion techniques, such as damming and filling, became more efficient and commercially available, the country's agricultural center had already moved west of New England. The positive correlation between area of salt marsh lost and urban growth suggests that urban development has been a large cause of coastal habitat destruction in New England. In greater Boston, 70% of the original salt marsh is now urban land (Fig. 3), and much was converted directly from salt marsh to residential and industrial land (Seasholes 2003).

Limitations of Using Historical Maps for Comparative Mapping

Historical maps and literature represent a rich data source and a valuable tool in overcoming the short-term nature of many ecological studies. Working with historical data also has its limitations. Assessing the accuracy of old maps is difficult. Ideally, several maps of each area from the same time could be analyzed and averaged to correct for inaccuracies, but a scarcity of accurate historical maps depicting salt marshes made repetition unfeasible in this study. RI's estimate is based on only one map, and ME's and NH's estimates are each based on two.

Historical maps were not available for the entire coastline. The data presented here provides only percentage estimates of loss, based on a subset of the coastline of each state. The historical maps used here as a representative sample of New England covered 2,220 km of coastline or 20% of the coastlines of RI, MA, NH, and ME. Published maps are also inherently biased by their intended purpose. The historical maps used in this study were all made for coastal navigation and had detailed coastal land use and were not particularly biased towards urban centers. Urban (e.g., Boston, MA, and Portsmouth, NH), suburban (e.g., Barrington, RI, and Kennebunk, ME), and rural areas (e.g., Plum Island, MA) were included in these maps.

Efficacy of Salt Marsh Conservation Efforts

The data in this paper can alternatively be approached as case studies. Where have salt marshes been conserved, where not, and why? Within the Ipswich, MA, map area, little salt marsh area (8%) has been lost. Low levels of urbanization (1.4%) and restoration efforts are probably responsible for the preservation of these marshes. The towns around Ipswich have worked with state environmental agencies and scientific institutions to undertake 56 restoration projects on the north shore of MA, at least 35 of which have been completed. Though the equivalency of restored marshes to pristine marshes is under debate (Zedler and Lindig-Cisneros [2000] report restored salt marshes to be <60% functionally equivalent to natural salt marsh), restored marshland is better habitat than asphalt for salt marsh flora and fauna.

The effectiveness of conservation is demonstrated in the Kennebunk, ME area. The area of salt marsh around Kennebunk has actually increased by 3%. This 3% could represent growth of salt marsh by natural processes or the extent of error in the estimation techniques. The fact that salt marsh coverage has not decreased is likely the result of explicit protection and management of wetlands within the Rachel Carson National Wildlife Refuge since 1966. The Ipswich and Kennebunk areas provide evidence that conservation and restoration are effective tools in preserving salt marshes.

The Future of Salt Marshes

In the U.S., recent declines in rates of salt marsh loss are encouraging, although the future of the remaining salt marshes in New England is uncertain. Loss estimates describe only the presence or absence of marshes; they communicate nothing of marsh health. No GIS data are currently available on the health of wetlands. In some states, environmental agencies are working to create GIS data layers that will assess salt marsh health (Tiner 2003; Pesch personal communication). The NWI is updating its digital database of wetlands (data currently available is from digitized photographs that were taken in the early 1980s), with a focus on heavily populated coastal areas (U.S. Fish and Wildlife Service 2002). Descriptive and timely data on wetlands will increase our understanding of the formidable threats to their existence and help focus conservation efforts.

Applications of Long-term Habitat Loss Estimates

Comparative mapping techniques using historical maps should be applied to other coastal ecosystems, particularly in regions with well-documented histories of land use. Already comparative mapping techniques have been successfully used to estimate changes in eelgrass, *Zostera marina*, cover in southeastern MA (Costa 1988), salt marsh in central California (Grossinger 2001; Van Dyke and Wasson 2005), and wetlands in the fenland region of southeastern England (Butlin 1995). Louis Agassiz visited coral reefs while employed by the U.S. Coast Survey in the 1800s, and good historical data may exist for a change analysis of that valuable habitat (Shalowitz 1964).

It is only with an historical perspective that current monitoring programs will succeed. Remnants of past land uses are often seen in the landscape today and can be mistaken for a natural state. Understanding the historical alterations to the natural state of a habitat can help resource managers answer the fundamental question of how best to reverse decades of human effects and restore a habitat to its natural state.

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