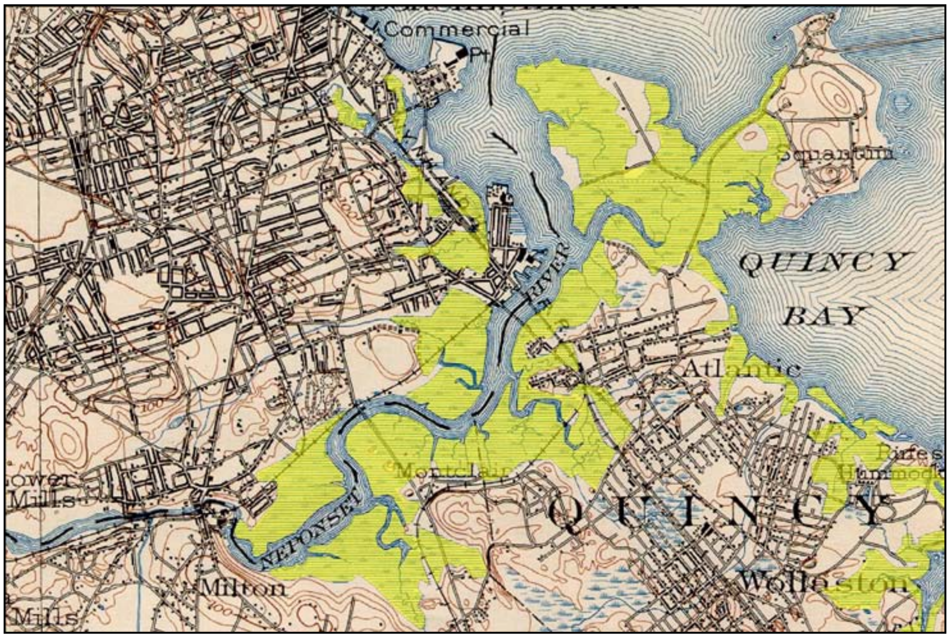
100 Years of Estuarine Marsh Trends in Massachusetts (1893 to 1995): Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands



A Cooperative Report by the Massachusetts Office of Coastal Zone Management, the U.S. Fish and Wildlife Service, and the University of Massachusetts

CZM

This report should be cited as follows:

Carlisle, B.K., R.W. Tiner, M. Carullo, I.K. Huber, T. Nuerminger, C. Polzen, and M. Shaffer. 2005. 100 Years of Estuarine Marsh Trends in Massachusetts (1893 to 1995): Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands. Massachusetts Office of Coastal Zone Management, Boston, MA; U.S. Fish and Wildlife Service, Hadley, MA; and University of Massachusetts, Amherst, MA. Cooperative Report.

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This project has been financed in part by the National Oceanic and Atmospheric Administration (NOAA), award No. NA17OZ1125 and by the U.S. Environmental Protection Agency (EPA), award No. CD98185401-1. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or EPA. The mention of trade names or commercial products does not constitute endorsement or recommendation for use.

100 Years of Estuarine Marsh Trends in Massachusetts (1893 to 1995): Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands

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February 2006

A Cooperative Report by the Massachusetts Office of Coastal Zone Management,
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EXECUTIVE SUMMARY

The Massachusetts Office of Coastal Zone Management, the U.S. Fish and Wildlife Service, and the University of Massachusetts Department of Plant, Soil, and Insect Sciences conducted an investigation of trends—losses, gains, and changes—of tidal emergent and shrub-scrub wetlands, or "estuarine marshes," for selected study areas in Massachusetts. The effective dates for the investigation were 1893, 1952, 1971, and 1995. The study area for this investigation included Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands. This investigation is the first of a three-part series that will provide a comprehensive examination of estuarine marsh trends for all of Massachusetts since the late 1800s.

Photo-interpreters used digital aerial photographs and maps to interpret estuarine marshes for each effective date and identify changes that occurred in the period between each date. The aerial photographs included color infra-red and black and white images from the mid-1990s, and black and white from the early 1950s and the early 1970s. The study also included an examination of the first series of topographic maps produced by the U.S. Geological Survey in the late 1800s and early 1900s. Though limited in terms of accuracy, these maps provide one of the few comprehensive sources available for information on the presence and extent of coastal wetlands at the turn of the 20th Century. The historical topographic maps are believed to under-represent the extent of coastal wetlands that were actually present at that time. Accounting for areas of omission and mis-classification, as well as areas where human activities and natural processes resulted in the creation of large amounts of estuarine marsh, investigators used the topographic maps to develop estimates of the estuarine marsh base in 1893.

For the entire time period covered by the investigation (from 1893 to 1995), estuarine marsh losses totaled over 15,000 acres for the study area. Gains of estuarine marsh offset some of these losses, and the net change figure is over 8,200 acres of estuarine marsh lost. For the entire time period, the average rate of estuarine marsh change was a net loss of 81 acres per year.

During the first study period—from 1893 to 1952—estuarine marsh losses totaled 10,464 acres and gains were 5,176 acres, resulting in a net loss of 5,288 acres. This period saw dramatic increases in industry and technology, high immigration rates, and a rapidly increasing population. Demand for real estate for commercial and residential development was strong, and the filling, diking, and draining of salt marshes went largely unchecked.

Losses of estuarine marsh from 1952 to 1971 totaled 3,354 acres, with gains of 815 acres and a net loss of 2,539 acres. During this period, the post-War population boom and industrial/commercial growth continued. Facilitated by major investments in transportation infrastructure, demand for areas to support commercial and residential development continued to be strong and regulatory protection was limited.

During the last period of the investigation, from 1971 to 1995, losses of estuarine marsh slowed, with period totals of 1,255 acres. Estuarine marsh gains were 797 acres for a net loss of 458 acres. Declining losses correspond with the establishment of wetlands regulatory protection programs, and losses that still occurred were offset in some part by natural gains.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

The Massachusetts Office of Coastal Zone Management (CZM), the U.S. Fish and Wildlife Service (USFWS), and the University of Massachusetts Department of Plant, Soil, and Insect Sciences (UMass) conducted an investigation of estuarine marsh trends—losses, gains, and changes—over three time periods. The areas selected for this investigation were: Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands (Figure 1). Within these areas, extensive estuarine marshes can be found on Cape Cod along Wellfleet Harbor, Little Pleasant Bay, and Barnstable Harbor. The wetlands class of estuarine marshes includes tidal emergent and tidal shrub-scrub wetlands, commonly known as "salt marshes."

The goal of the study was to inform coastal managers on recent and historic trends of estuarine marshes, providing information and context on these resources for the development and implementation of assessment, conservation, and restoration strategies. This investigation is the first of a three-part series designed to provide a statewide assessment of estuarine marsh trends. This report describes the methods and results of the trend analysis and offers brief discussion on the findings.

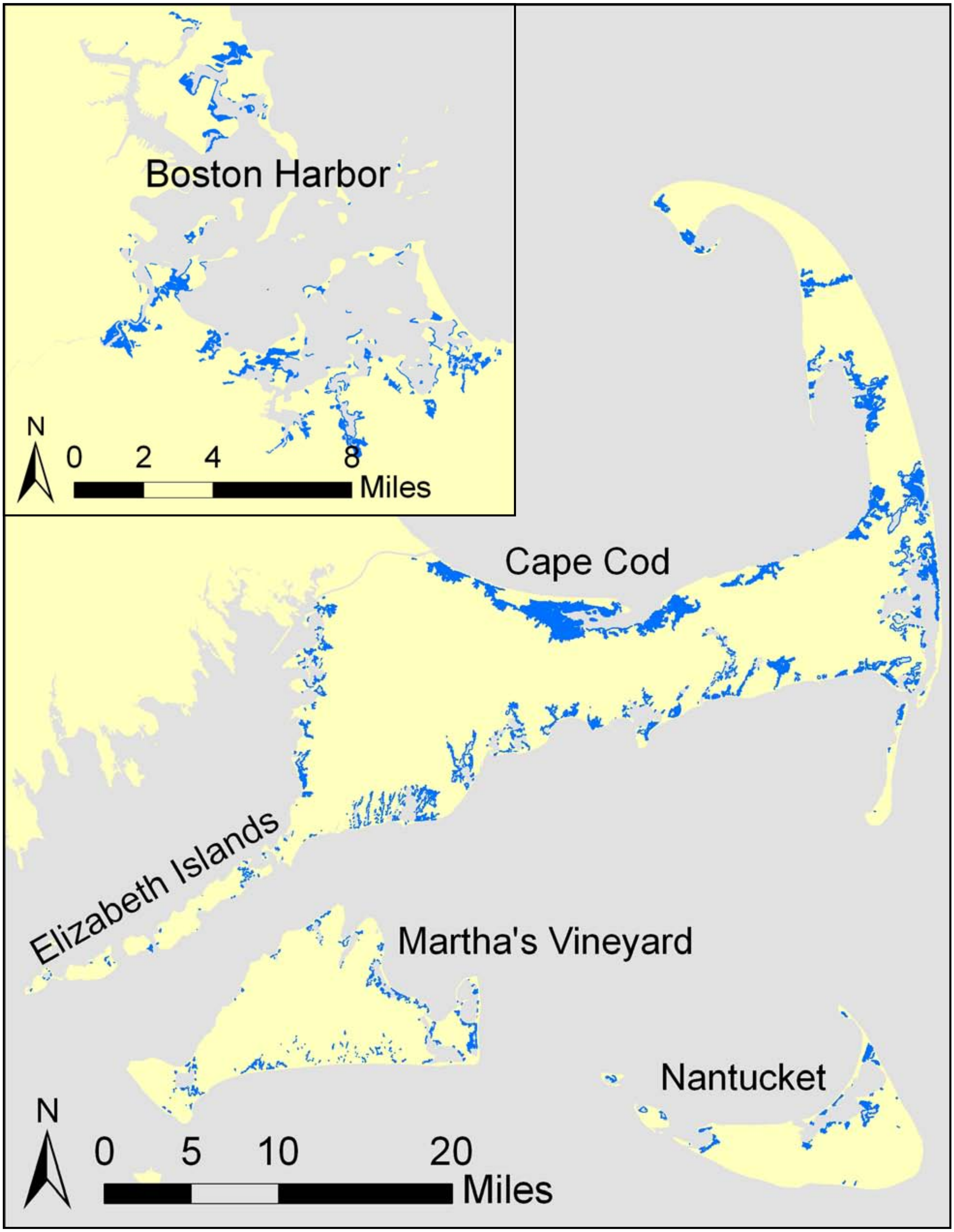

Figure 1. Distribution of coastal wetlands in 1995 for project study areas. Inset shows Boston Harbor region. (Size of wetlands slightly exaggerated for display purposes.)

METHODS

The purpose of this study was to document trends in estuarine marshes for three time periods: 1) the late 1800s to the 1950s, 2) the 1950s to the 1970s, and 3) the 1970s to the 1990s. The source data used for this project consisted of historical U.S. Geological Service (USGS) maps for the late 1800s and aerial photographs for the 1950s, 1970s, and 1990s (Table 1). The effective dates used throughout this report are based on the median date of the data sources: 1893, 1952, 1971, and 1995.

Table 1. Source data types, dates, and scales by study area region.

Region	Data layer	Type	Source Data and Date	Scale
Boston	Historical USGS maps	Raster	Scanned, rectified maps;1903	1:62,500
	1950s B&W aerial photos	Raster	Scanned, rectified B&W photos; Aug. and Oct. 1952	1:20,000
	1970s B&W aerial photos	Raster	Scanned, rectified B&W photos; June, July, and Aug. 1971	1:20,000
	1990s MA mapped wetlands	Vector	CIR photography; March and April 1990	1:12,000
	1990s NWI mapped wetlands	Vector	B&W photography; March and April 1995	1:40,000
Cape Cod	Historical USGS maps	Raster	Scanned, rectified maps; 1893	1:62,500
	1950s B&W aerial photos	Raster	Scanned, rectified B&W photos; June, July, and Oct. 1952	1:20,000
	1970s B&W aerial photos	Raster	Scanned, rectified B&W photos; July and Aug. 1971	1:20,000
	1990s MA mapped wetlands	Vector	CIR photography; March and April 1993	1:12,000
	1990s NWI mapped wetlands	Vector	B&W photography; March and April 1995	1:40,000
Nantucket, Martha's Vineyard, and the Elizabeths	Historical USGS maps	Raster	Scanned, rectified maps; 1893 and 1894	1:62,500
	1950s B&W aerial photos	Raster	Scanned, rectified B&W photos; Oct. 1951; July and Oct. 1952	1:20,000
	1970s B&W aerial photos	Raster	Scanned, rectified B&W photos; Aug. and Oct. 1971	1:20,000
	1990s MA mapped wetlands	Vector	CIR photography; March and April 1993	1:12,000
	1990s NWI mapped wetlands	Vector	B&W photography; March and April 1995	1:40,000

Geographic information system (GIS) technology was used to interpret wetland changes and construct a digital geo-spatial database for data compilation and analysis. The database contains the base estuarine marsh layers for each effective date (1893, 1952, 1971, and 1995), as well as the trends layers for each time period (1893 to 1952, 1952 to 1971, and 1971 to 1995). Figure 2 depicts a graphical representation of the process of developing the trends and base layers. The 1995 estuarine marsh base was positioned on the 1971 aerial photography, allowing photo-interpreters to identify the 1971 to 1995 trends and then to produce the 1971 base layer. Similarly, the 1971 base was overlain on 1952 aerial photography, generating the 1952 to 1971 trends layer and the 1952 base. Finally, the 1952 base was placed on the 1893 map, resulting in the 1893 to 1952 trends and 1893 base layers.

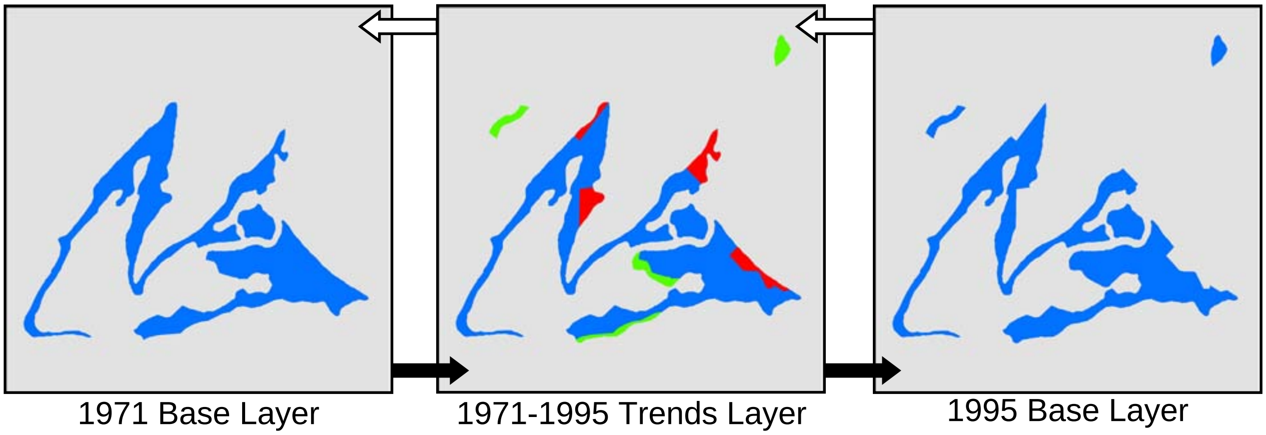

Figure 2. Example of trends and base layer development process. Estuarine marsh shown in blue, losses in red, and gains in green. White arrows depict data development sequence; black arrows show chronological order.

Source Imagery and Base Data

Table 1 lists the source data types, dates and scales by study area region. The aerial photographs from the 1950s and 1970s were acquired from the University of Massachusetts-Amherst, Department of Natural Resources Conservation. They had been used previously to map land use and land cover for Massachusetts. Each individual photograph was scanned at 300 dots per inch (DPI) by New England Blueprint Inc. and then geo-rectified to the current Massachusetts ortho-base (2001 for the mainland, 2003 for the Islands) by UMass GIS staff. The control points for the geo-rectification were derived from the best available features, including road intersections, bridge crossings, and in some cases buildings.

The historic USGS topographic quadrangle maps were obtained from the University of New Hampshire Library's Historic USGS Maps of New England and New York website (http://docs.unh.edu/nhtopos.htm). The maps were scanned by staff at the University of New Hampshire Library. Because of the size of the originals, each original 15 minute (1:62,500k) map was scanned in four separate quarters at 200 DPI. CZM used the 2001/2003 ortho-base to rectify the images. For the historic USGS topographical maps the control points were latitude and longitude graticules.

To develop the 1995 estuarine marsh base layer, investigators used digital geo-spatial wetlands data from two sources:

1. The Massachusetts Wetland Conservancy Program (WCP), posted at: http://www.mass.gov/mgis/wetdep.htm.
2. The USFWS National Wetlands Inventory (NWI) Program, posted at: http://wetlands.fws.gov.

These sources included both coastal and inland wetlands, as well as vegetated and non-vegetated types. The WCP data were mapped at a larger scale than that of NWI; this allowed for the inclusion of smaller patches of wetlands. The NWI data had more detail in classification of types and generally provided more detail distinguishing linear water features (e.g., creeks and major ditches) from the vegetated portions of the marshes.

Using GIS geo-processing techniques, all polygons from the state WCP wetlands data that were classified as salt marsh (coded as SM) were extracted and made into a separate layer. Similarly, from the NWI base, areas classified as estuarine tidal emergent or scrub-shrub marsh (coded as E2EM and E2SS plus additional modifiers, including polygons with dual codes such as E2EM/US) were extracted and made into a separate layer. The estuarine marsh polygons from the NWI were used as the foundation for the base layer, and areas where the WCP had salt marsh but NWI did not were added. In these cases, the WCP polygon was retained, but the coding was converted to use the NWI classification (i.e., salt marsh [SM] was re-coded E2EM).

Interpretation Procedures

Wetlands interpretation and digitizing was conducted on-screen using image (raster) data as the base to develop the polygon layers (vector data). This process was efficient and allowed for work with a very large study area over four points in time. The process, however, did not permit stereoscopic interpretation, which does aid in recognition of certain features. For example, it was sometimes difficult to separate flooded salt marsh at the lower end of the inter-tidal zone (i.e., Smooth Cordgrass or *Spartina alterniflora*) from aquatic beds (e.g., Eelgrass or *Zostera marina*). Some narrow fringing patches of salt marsh may have escaped detection on the black and white images. In some cases, distinguishing emergent from scrub-shrub wetlands was difficult.

Alignment problems invariably arise when data derived from one source of imagery are projected onto another and combined. Interpreters had to consider factors such as misalignment and poor image quality and used their best judgment to determine whether information was sufficient to support the classification of wetland loss, gain, or change in type.

Trend Categories and Attribution of Cause

Wetland changes were classified to one of four broad “trend” categories (Table 2). Wetland areas that did not change from one period to the next were simply classified as "No Change." Areas where changes were from one estuarine type to another (i.e., estuarine emergent to estuarine scrub-shrub and vice versa) were labeled as “Change in Type.” The “Gain” category represents new marsh—areas of estuarine marsh that were not present in the previous time period. The “Loss” category includes all areas where estuarine marsh were present in one period and not in the next. The losses were attributed to one of six trend types (Table 2). Losses to “Agriculture,” “Developed,” “Undeveloped,” and “Open Water” were determined with the assistance of state land use data (posted at: http://www.mass.gov/mgis/lus.htm). The land use data were available for all areas for the 1990s and 1970s, but only available for Cape Cod for the 1950s, and therefore the loss category “Undetermined” was used where estuarine marsh loss cause could not be specified. Estuarine marshes that changed into another type of wetland (e.g., palustrine or intertidal flat) were recorded as “Loss to Other Wetland.” It is important to note that while Loss to Other Wetland represents actual lost estuarine marsh, it does not contribute to a net loss of wetlands.

Source Data Limitations

As with any remotely sensed data, the quality and resolution of the source imagery influence the capability of detection. As time progresses, so too does technology, and in the time covered by this study there were definite advancements in both data capture (aerial photography) and processing (triangulation and ortho-rectification).

Table 2. Estuarine marsh trend change categories.

Trend Category	Description
No change	Same class from one period to next
Change in Type	Change in estuarine marsh class from one period to next (e.g., from E2EM to E2SS, E2SS to E2EM, and E2EM/US to E2EM)
Gain	Gain of class E2EM or E2SS from one period to next
Loss	Loss of estuarine marsh to one of the following types: • Developed (includes LU codes 7-13, 15-19) • Agricultural (includes LU codes 1, 2, 21) • Undeveloped filled or drained (includes LU codes 3, 4, 6, 14) • Open water (includes LU code 20 and class MUS) • Other wetland (includes classes PEM, PSS, PFO, E2AB, E2US) • Undetermined

In the estuarine marsh layers, there are small areas of both inclusions (other features within mapped wetlands such as creeks or ditches) and exclusions (wetland omissions). For this project, more inclusions than exclusions are expected since salt marshes are readily identified through aerial photographs and the scale used permitted small patches of marsh to be detected and delineated. Ditches or very small, narrow fingers of upland may be included within the mapped wetlands.

The 1950s and 1970s black and white aerial photographs were of variable quality. These photographs were originally used by the state to map land use and cover, and during this process, typically every other photograph in a flight line was altered by pen markings made directly on the photo print. In some cases, the photographs had good resolution and proper exposure with no foreign markings or damage, but in other cases, the photos were overexposed, altered by pencil or ink markings, and even slightly damaged from use. Where an image was overexposed, it was difficult to determine whether a change had occurred in the "white-out" area. Some emergent fringe polygons may appear as unconsolidated shore or mixed unconsolidated shore (unvegetated wetlands) and some areas of regularly flooded salt marshes may have been underwater at the time of photograph capture.

Though limited in terms of data quality, the 1893-era USGS topographical maps provide one of the few comprehensive data sources available for information on the presence and extent of tidal wetlands at the turn of the 20th Century.[1] To establish the estuarine marsh areas from this data source, GIS technicians used specific map symbology to digitize polygons. As depicted in Figure 3, the symbology that was used to define tidal marshes was the traditional wetland symbol overlain by fine horizontal lines.

[1]Another good source are the historical "T-sheets" (1832-1898 era) issued by the U.S. Coast and Geodetic Survey. These were not selected because: 1) coverage was incomplete for study area, and 2) extent of coverage on sheets often did not include upland extent of estuarine marsh systems.

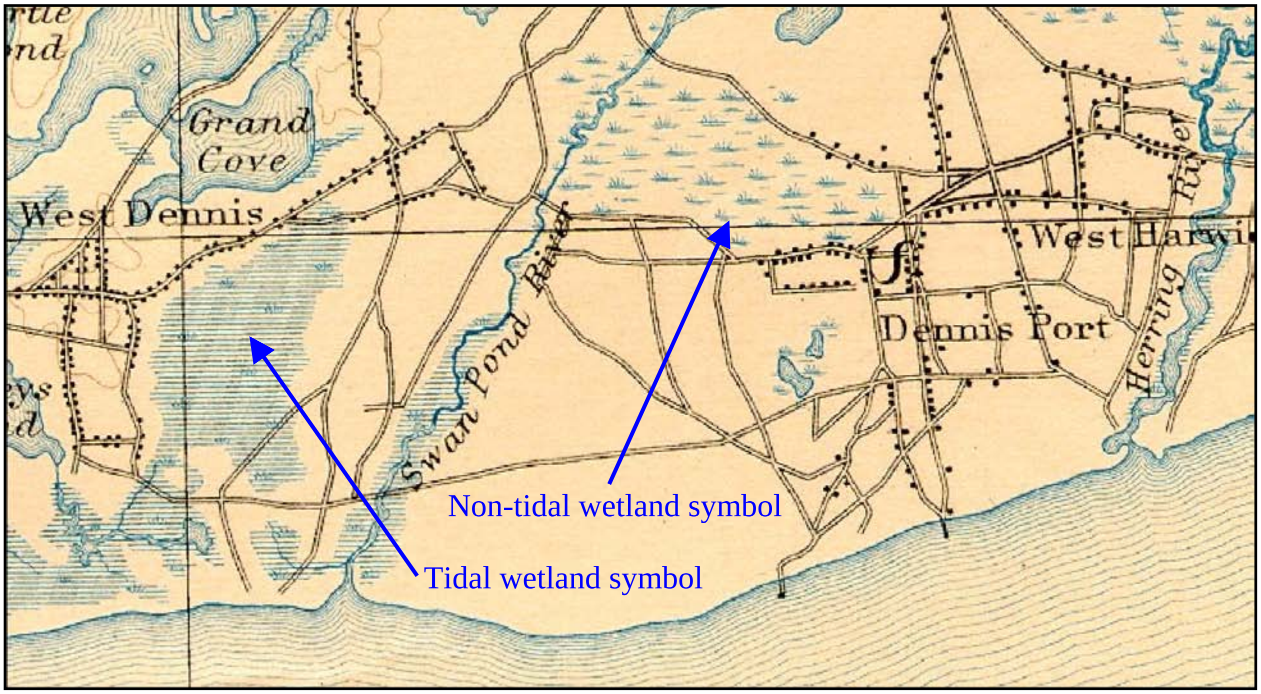

Figure 3. Example of 1893 historic USGS map with wetland symbols.

Use of the 1893 Data

In comparing the 1893 maps and 1952 aerial photographs, it is evident that wetland areas that were very likely tidal in 1893 were not delineated as such (Figure 4), and areas where there was a high probability of supporting fringing marsh along back barrier beaches and tidal rivers and creeks were not mapped at all (Figure 5). As a result of these mapping omissions, significant areas of estuarine marshes that almost certainly existed in the late 1800s were not recorded on these maps. The cumulative omission of mapped estuarine marsh from the 1893 period affects both the 1893 base estuarine marsh data and 1893-1952 trends data. For the 1893 base data, the total area of mapped estuarine marsh is lower than what is likely to have been present. For the 1893-1952 trends, the gains derived from comparing the mapped tidal wetlands to those delineated from 1952 photography are much higher than what is likely, both naturally and through human-induced change.

To address this issue, investigators conducted an examination of the 1893 base and 1893-1952 trends data to generate a better estimate of the amount of estuarine marsh present at the turn of the 20th Century, and therefore the actual gains between 1893 and 1952. The revised estimate accounted for: 1) several areas where there was a high probability of estuarine marsh omitted on the 1893 maps, 2) several areas that were classified as non-tidal but were very likely tidal on the 1893 maps, 3) several areas where human activities resulted in the creation of large amounts of estuarine marsh between 1893 and 1952 (e.g., the creation of a breakwater at Long Point in Provincetown; construction of Logan Airport in Boston Harbor; filling of South Bay), and 4) several areas where natural processes produced significant gains (e.g., the migration southward of Nauset beach and the northward accretion of Monomoy Island). The revised estimates of 1893 base and 1893-1952 trends data are reported in the Results section and are used throughout this report. The wetlands extent information derived from the historic USGS topographical maps should be viewed as approximate and used within this context.

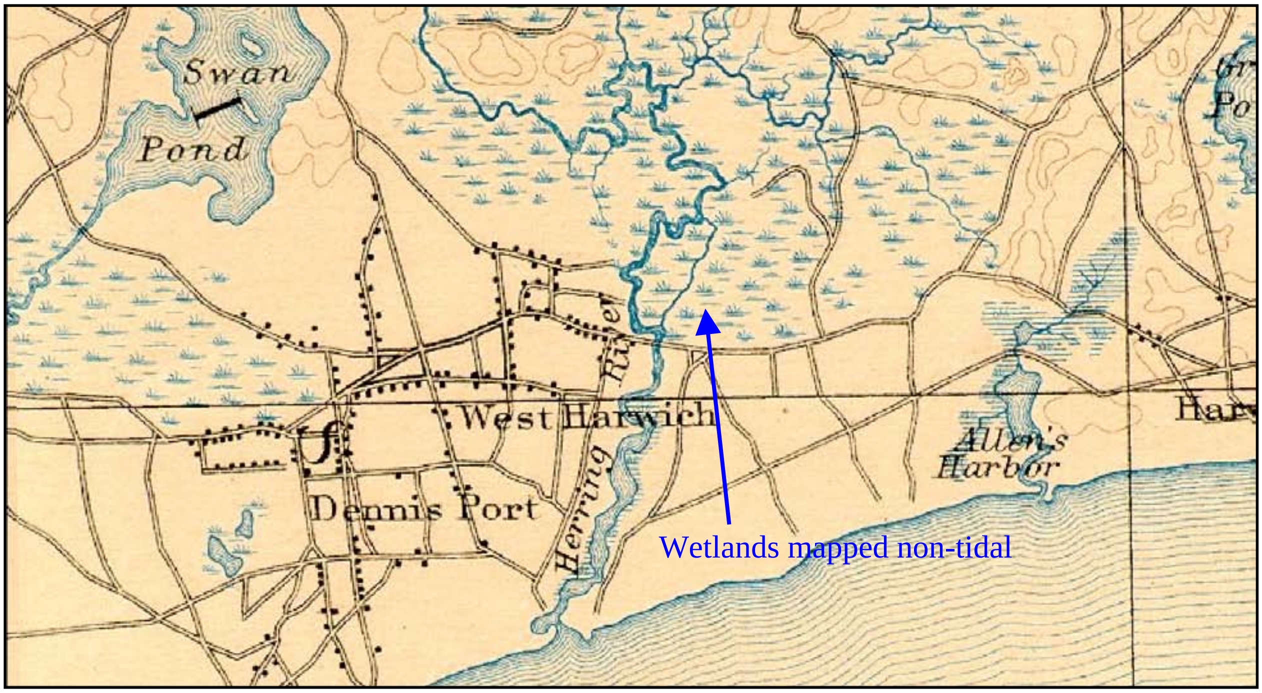

Figure 4. 1893 historic USGS map showing Herring River, Harwich: Example of wetlands mapped as non-tidal that were likely tidal.

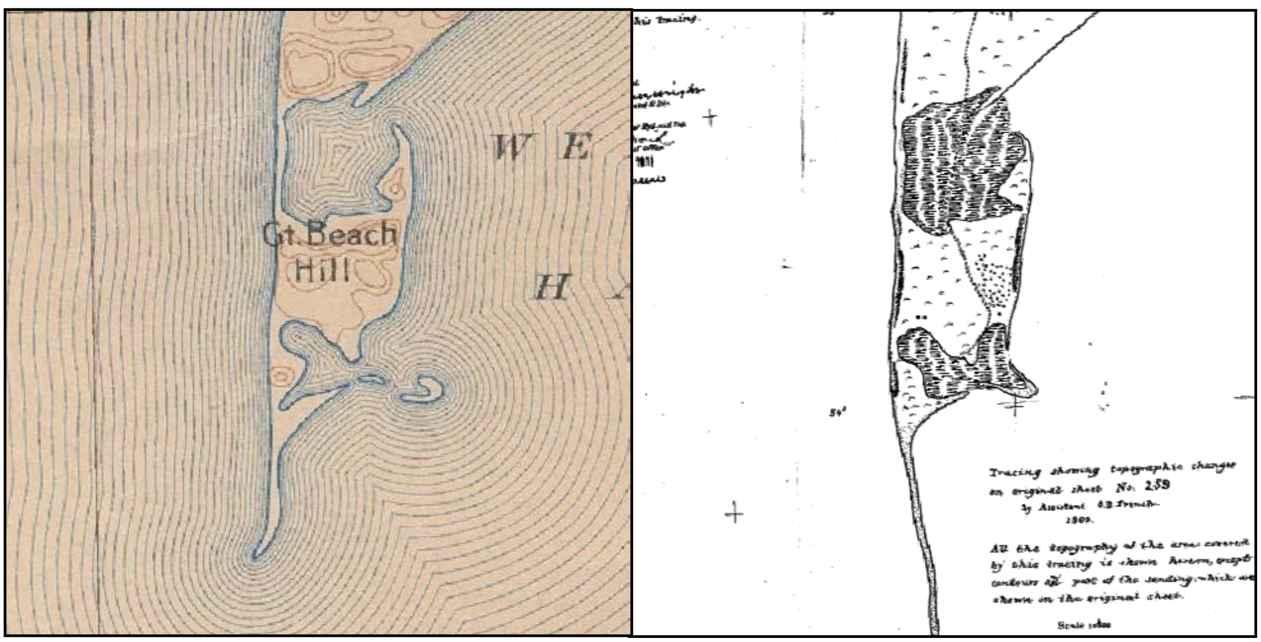

Figure 5. 1893 historic USGS map and 1909 U.S. Coast and Geodetic Survey T-sheet showing Great Beach Hill, Wellfleet: Example of back barrier system where tidal wetlands likely existed and were displayed on T-sheet but were not shown on USGS maps.

Precision and Accuracy

As with any exercise in remote sensing, especially with different types, sources, and time of data, there are limitations to the precision and accuracy of the results. Precision deals with the level of detail and repeatability of measurements; accuracy is the degree to which the information matches true or accepted values. The types of estimated error in remote sensing and GIS mapping investigations focus primarily on positional precision and accuracy and attribute precision and accuracy.

Positional, or spatial, precision for this study was limited by the scale of source imagery and the ability of interpreters to delineate a unit of interest. For this study, the minimum mapping unit was established at 0.25 acre. In some cases, especially with the more recent source imagery, interpreters were able to identify and map units smaller than 0.25 acre.

Efforts were made to quantify the horizontal positional accuracy for this study. Since the vertical position, or elevation, was not determined in this study, vertical positional accuracy was not assessed. To quantify horizontal positional accuracy, various sources for error must be examined. The sources of error vary depending on the type and method of data development, but can be distilled into two groups: source and interpretation accuracy. Source accuracy is a measure of how well the information in question—in this case aerial photographs and topographical maps—fits to an independent source of higher accuracy—in this case the current set of Massachusetts ortho-rectified photographs, or “base” maps. Ortho-rectified imagery has been corrected to become a geospatial accurate representation of the ground’s surface through photogrammetric techniques and meet National Map Accuracy Standards (NMAS) for 1:5,000 scale maps. Interpretation accuracy is how well the item of interest has been mapped or delineated and can include errors that are created in the field as well as those made in the process of digitizing the information.

The accuracy of the image source can be determined through a process that takes a number of control points from the image in question and compares them to the “true” points on the ortho base map. The differences between each image and true point are called residual errors, and by applying an established equation, a final measure of fit can be determined. This process and equation is known as the Root-Mean-Square Error (RMSE) method and is the standard for estimating GIS data positional accuracy (FGDC, 1998).

For each data source except the 1995 imagery, the RMSE was calculated. A minimum of five control points were placed on each source image, spread as widely over the image extent as possible, and using GIS geo-referencing tools, the RMSE was calculated for each image. For the historic USGS topographical maps, the control points were latitude and longitude graticules (adjusted for datum transformation). For the 1952 and the 1971 aerial photographs, the control points were derived from the best available features, including road intersections, bridge crossings, and in some cases buildings. The number of individual images and control points for each period is listed in Table 3.

Since it was not feasible to access the source imagery that was used by NWI and WCP staff to create the original wetland data that served as the base for the 1995 estuarine marsh layer, a substitute method had to be employed to assess the source data accuracy. The NMAS define the

Table 3. Number of images and control points for positional RMSE analysis.

Period and Image Type	Numbers of Images Assessed	Total Points
1893 USGS topo maps	36	324
1952 B&W aerial photographs	11	55
1971 B&W aerial photographs	11	55

acceptable error for published maps based on the map scale. The two sources of data for the 1995 estuarine marsh layer had different scales, 1:12,000 for the WCP data and 1:40,000 for the NWI. The NMAS acceptable error for 1:12,000 is within 33.3 feet and for 1:40,00 is within 66.7 feet.

Interpretation accuracy is characterized as the error inherent in the interpreter's ability to consistently determine and place a line delineating the wetland—or more specifically, the signature of the wetlands from the specific source image—not the actual wetland on the ground[2]. This error is largely dependent on the scale and resolution of the source imagery. The values used to estimate the interpreter's error for this study were taken from an assessment of shoreline change studies by Crowell et al. (1991).

Table 4 contains the positional accuracy error estimates for the base and trends data. Using the RMSE method, the source error values and the interpretation error values were squared, summed, and then the square root was taken to derive the total error estimate. Because of the two image sources for the 1995 data, the results for the 1:12,000 and the 1:40,000 have been averaged. To derive the period estimates for the trend data, again the RMSE method was used, and the error estimates for the two applicable time points were squared, summed, and then the square root was taken.

Table 4. Positional error estimates for base and trends data (in feet).

Base data	**1893**	**1952**	**1971**	**1995 a**	**1995 b**	**1995**
Scale	1:62,500	1:20,000	1:20,000	1:12,000	1:40,000	
Source error	14.8 *	30.5 *	32.5 *	33.3 **	66.7 **	
Interpretation error	51.3	16.4	16.4	9.8	32.8	
Total error	**53.3**	**34.6**	**36.4**	**34.7**	**74.3**	**54.5**
Total error in acres	**0.21**	**0.09**	**0.10**			**0.21**
Trends data	**1893-1952**		**1952-1971**		**1971-1995**	
Total error	**63.6**		**50.2**		**65.6**	
Total error in acres	**0.29**		**0.18**		**0.31**	
Notes: * = Value derived from RMSE control point process, ** = Estimate from National Map Accuracy Standards						

[2] The location of the actual wetland boundary is variable as well, depending on the wetland in question, the method used, and the individuals conducting the delineation.

The total error estimates mean that for a certain data set, any given point has a circle around it whose radius is the total error estimate in feet (Figure 6); the area of the circle is the total estimated error (shown in Table 4 as area in acres). In other words, for that given point, its actual location could be anywhere within the circle of possible error.

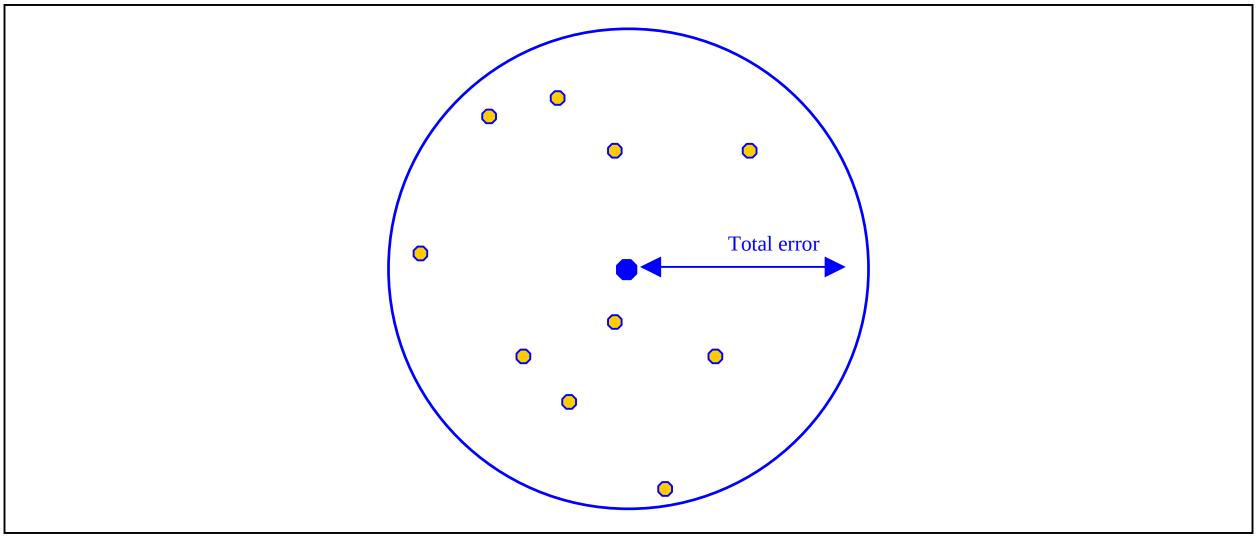

Figure 6. Graphic representation of total error for hypothetical point.

To address issues of attribute precision, specific classes of wetlands to be used for the study were selected based on the level of detail that the interpreters could comfortably discriminate. These classes are based on the Cowardin system adopted by the NWI (Cowardin et al., 1979) and the ones used in the study are listed in Table 5. In many cases the interpreters were able to go beyond the class to the subclass level with water regime modifiers, but this information was not used in the trends assessment.

Table 5. Wetland classes for trends study.

System	Subsystem	Class
Marine (M)	Intertidal (2)	Unconsolidated shore (US)
Estuarine (E)	Subtidal (1)	Unconsolidated bottom (UB)
		Aquatic bed (AB)
	Intertidal (2)	Unconsolidated shore (US)
		Emergent (EM)
		Scrub-shrub (SS)
Palustrine (P)	none	Emergent (EM)
		Scrub-shrub (SS)
		Forested (FO)

Attribute accuracy is a measure of how well the wetland data developed from a remote source match the characteristics of the actual wetland in the field. Because of limited resources, a direct assessment of attribute accuracy was not possible for this study.[3] Instead, investigators used the attribute accuracy results from three studies that looked at the accuracy of mapping wetlands from aerial imagery (Table 6). In these studies, verification was completed to determine if the mapped wetland represented what was present on the ground (the "true" value). Two of the studies used field surveys to verify the mapped information; the third used mapped hydric soils. Although there are regional differences, these studies show that a high level of attribute accuracy can be achieved both in mapping actual wetland and in classifying wetland types through the use of remote sensing with aerial imagery.

Table 6. Studies reporting attribute accuracy of wetlands mapped from aerial imagery.

Study source	Accuracy	Accuracy Description	Wetland Types	Study Area
Nichols, 1994	100%	NWI mapped wetland = actual wetland	All	Maine
Nichols, 1994	97%	NWI wetland class = actual wetland class	All	Maine
Kudray and Gale, 2000	100%	NWI mapped wetland = actual wetland	Non-forested	Michigan
Melloh et al, 1999	89%	NWI mapped wetland = hydric soils	All	Alaska

[3] In addition, with the absence of corroborating evidence, it would be impossible to conduct this assessment for historic data.

RESULTS

Findings are presented for the entire study area and then for each of the individual regions: Boston Harbor; Cape Cod; and Nantucket, Martha's Vineyard, and the Elizabeth Islands. The 1893 results reported here are from the revised estimates of tidal marsh area as described in the Methods section. Table 7 compares the area of estuarine marsh actually depicted on the 1893 USGS historical maps and the revised estimates of estuarine marsh used in this report. Error estimates stated in the previous section have not been applied to these results.

Table 7. Area (acres) of estuarine marsh shown on 1893 maps and revised area based on estimates by investigators.

	1893 mapped	1893 estimated
Boston Harbor	4,584.83	5,325.67
Cape Cod	18,002.29	19,817.94
Nantucket, Martha's Vineyard, and the Elizabeth Islands	994.68	2,144.59
Study Area	**23,581.81**	**27,288.19**

Entire Study Area

Table 8 and Figure 7 show the estuarine marsh acreage for the study area and for the individual regions, while Table 9 lists the trends results for the study area, including total gains and losses as well as rates of change. In 1893, the study area had an estimated 27,288 acres of estuarine marshes. From 1893 to 1952, net losses (losses offset by gains) of 5,288 acres reduced the total area by 19 percent to just over 22,000 acres. During this period, the annual average net change rate was a loss of almost 90 acres per year. Over the next 19 years—from 1952 to 1971—the net change in estuarine marsh area was a loss of more than 2,500 acres at an average net change rate of 43 acres lost per year. For the last period of the investigation—from 1971 to 1995—more than 450 acres of estuarine marsh were lost, with a net change of about 8 acres lost per year. The 1995 estuarine marsh acreage represents 70 percent of the 1893 acreage, and total losses of estuarine marsh during time extent of this study were 8,285 acres. Losses and rates of loss curtailed significantly with each subsequent time period. Most of the losses occurred prior to the 1970s.

Table 8. Estuarine marsh acreage over four time periods for regions and study area.

Region	1893 estimated	1952	1971	1995
Boston Harbor	5,325.67	2,819.36	2,038.76	2,000.29
Cape Cod	19,817.94	17,069.25	15,568.20	15,235.31
Nantucket, Martha's Vineyard, and the Elizabeth Islands	2,144.59	2,111.89	1,853.40	1,767.65
Study Area	**27,288.19**	**22,000.50**	**19,460.36**	**19,003.25**

Table 9. Cumulative trends in estuarine marsh change for study area (values in acres; n/a is not available).

Trend	1893 to 1952	1952 to 1971	1971 to 1995
Gain	5,176.66	815.11	797.41
Gain rate (acres/year)	87.74	42.90	33.23
Loss	-10,464.35	-3,354.21	-1,255.43
Loss rate (acres/year)	-177.36	-176.54	-52.31
No Change	13,126.03	18,466.83	18,098.34
Change in Type	n/a	178.98	104.37
Net Change	**-5,287.69**	**-2,539.10**	**-458.02**
Net rate (acres/year)	**-89.62**	**-43.04**	**-7.76**

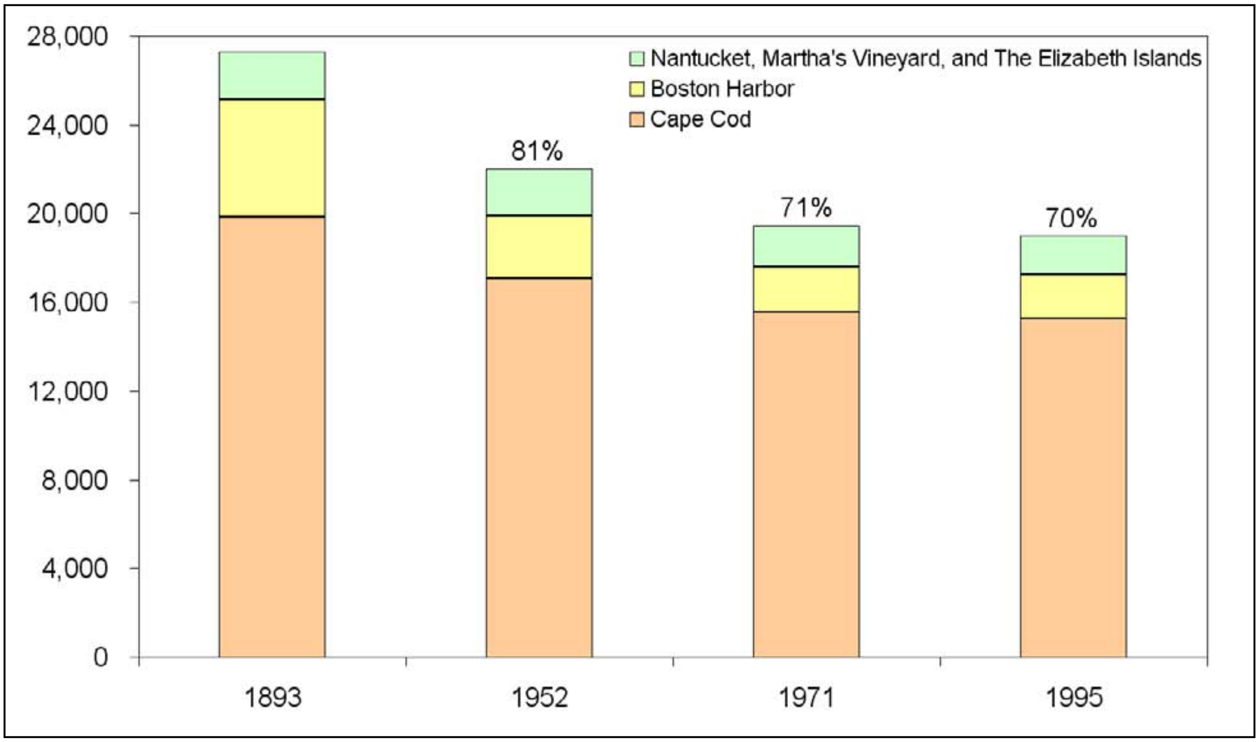

Figure 7. Area (acres) of estuarine marsh over four time periods of study. Value noted is percent of the 1893 estuarine marsh area.

Trends for Boston Harbor

About 5,326 acres of estuarine marsh are estimated to have existed in the Boston Harbor region in 1893. This figure was reduced by a net loss of 2,506 acres for a total of 2,819 acres in 1952. Another 780 acres of net loss occurred by 1971, with a new estuarine marsh total of 2,039 acres. From 1971 to 1995, there was a net decline of 38 acres, and the 1995 estuarine marsh total was 2,000 acres. Causes of wetland loss are shown in Table 10 and graphically depicted in Figure 8. Because land use data was not available for the Boston Harbor region in the 1952 era and resources were not available to support the photo-interpretation for each loss polygon, most of the nearly 3,000 acres of estuarine marsh loss from 1893 to 1952 could not be characterized.

Table 10. Estuarine marsh trends for Boston Harbor (values in acres; n/a is not available).

Trend	1893 to 1952	1952 to 1971	1971 to 1995
Gain	**482.06**	**249.60**	**158.14**
Loss	**-2,988.37**	**-1,030.15**	**-196.58**
Loss to Agriculture	n/a	0.00	0.10
Loss to Developed	n/a	-671.74	-45.78
Loss to Natural Upland	n/a	-234.71	-35.57
Loss to Open Water	-189.17	-86.99	-115.13
Loss to Other Wetland	-21.86	-36.72	0.00
Loss Undetermined	-2,777.34	-	-
No Change	**1,596.46**	**1,745.93**	**1,825.37**
Change in Type	n/a	**43.41**	**16.94**
Net Change	**-2,506.31**	**-780.55**	**-38.44**

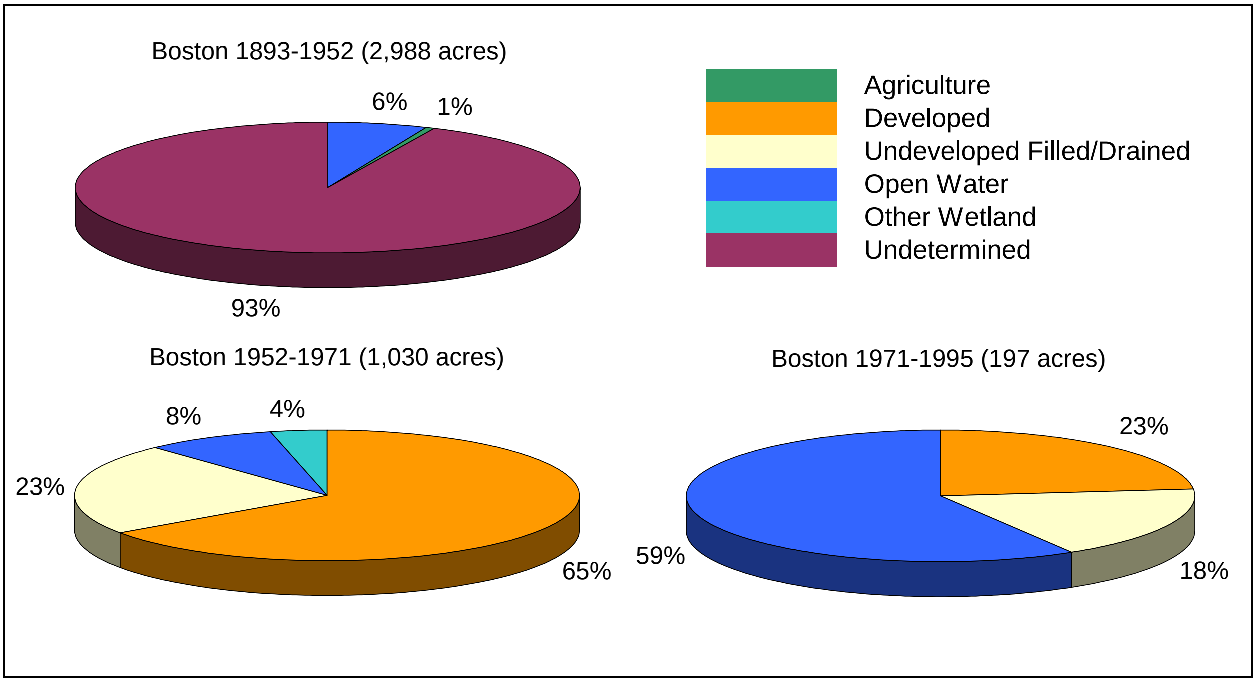

Figure 8. Categories of estuarine marsh loss for Boston Harbor.

Figure 9 shows salt marsh trends from 1983 to 1952 for the mouth of the Neponset River in Boston and Quincy. Note massive areas of upland fill throughout this region, primarily for commercial development and transportation infrastructure (e.g., roads and airport).

Losses during the 1952 to 1971 period amounted to 1,030 acres, of which 78 percent were conversions to upland. Gains amounted to 250 acres, reducing the net loss of estuarine marsh acreage to 781 acres. Salt marsh trends from 1952 to 1971 for the Mystic River estuary are depicted in Figure 10. In this area there was a complete loss of estuarine marshes in the mouth of the river due to filling, dredging, and damming.

Between 1971 and 1995, estuarine marsh losses declined significantly. Much acreage had been filled prior to this time, and state law (the Jones Act passed in 1963) offered new protections of estuarine marsh area. Nonetheless, 197 acres of estuarine marshes were lost, whereas 158 acres were created, producing a net loss of 38 acres for the region. Almost 60 percent of the loss was attributed to conversion to open water, and 41 percent of the marsh loss was attributed to conversion to upland. Figure 11 shows estuarine marshes trends from 1971 to 1995 in the Neponset River—note losses to commercial development.

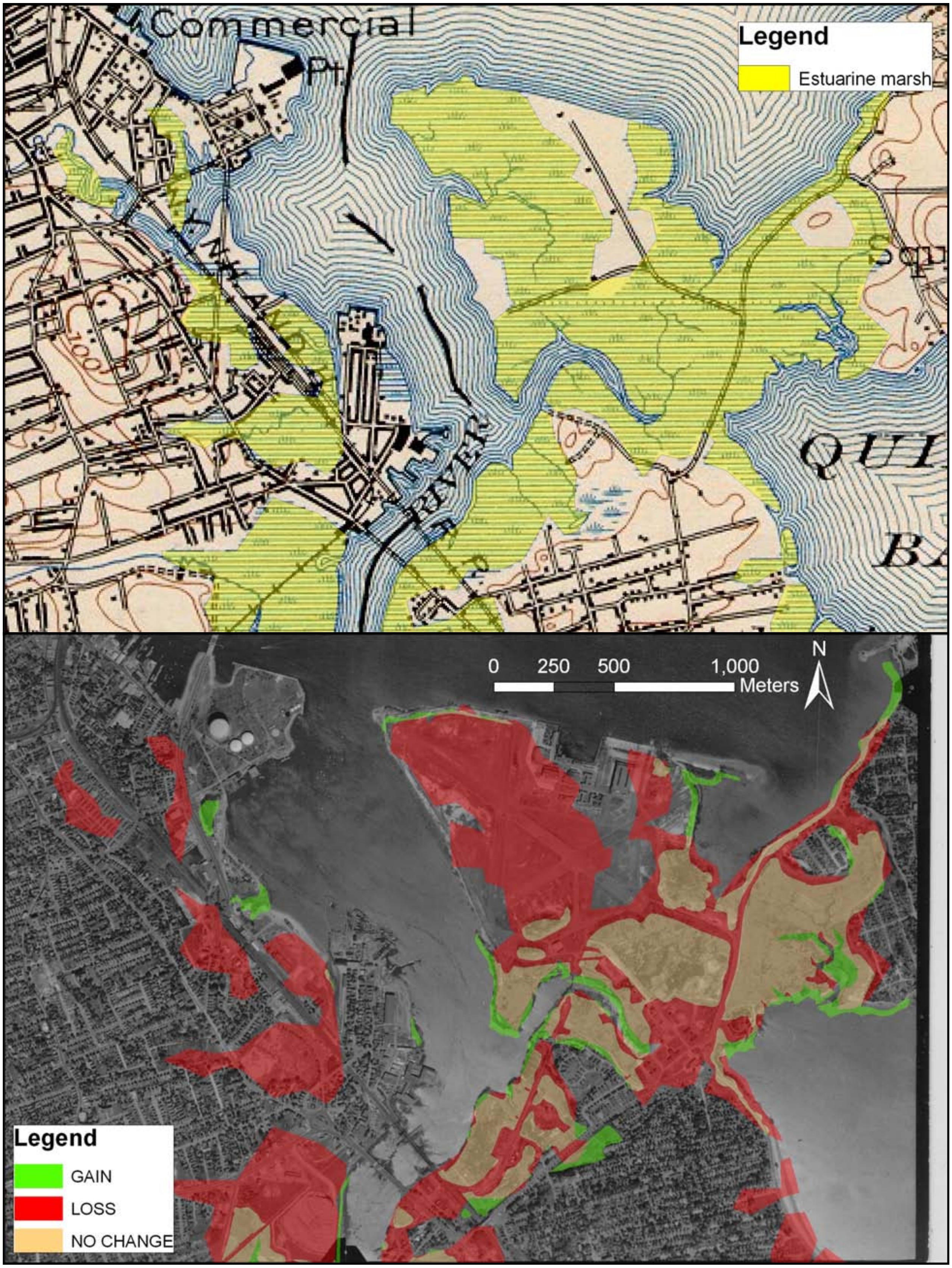

Figure 9. Neponset River, Boston/Quincy: 1893 map with mapped estuarine marsh (top) and 1952 aerial photograph showing 1893-1952 trends (bottom).

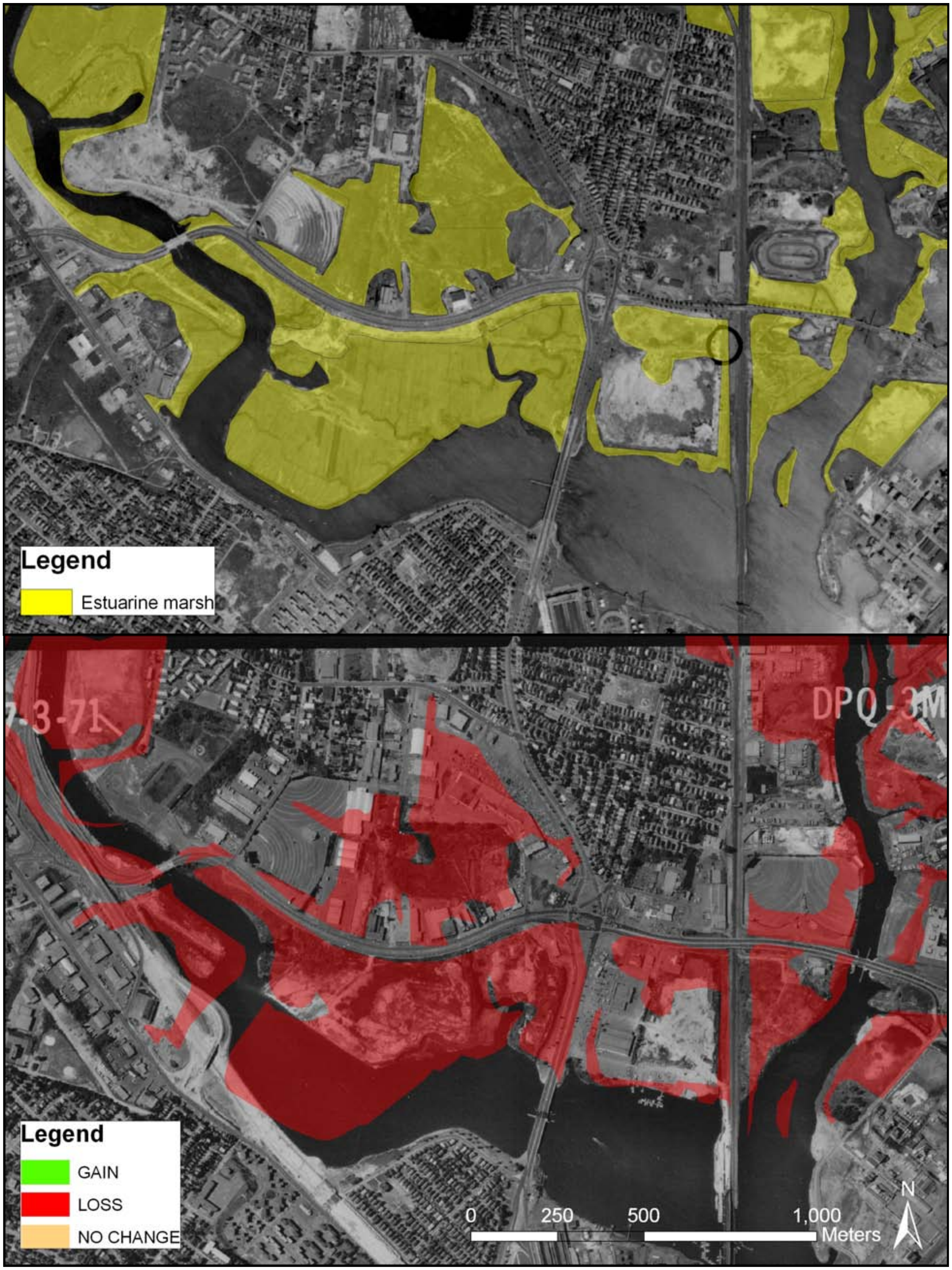

Figure 10. Mystic River, Somerville/Medford: 1952 aerial photograph with mapped estuarine marsh (top) and 1971 aerial photograph showing 1952-1971 trends (bottom).

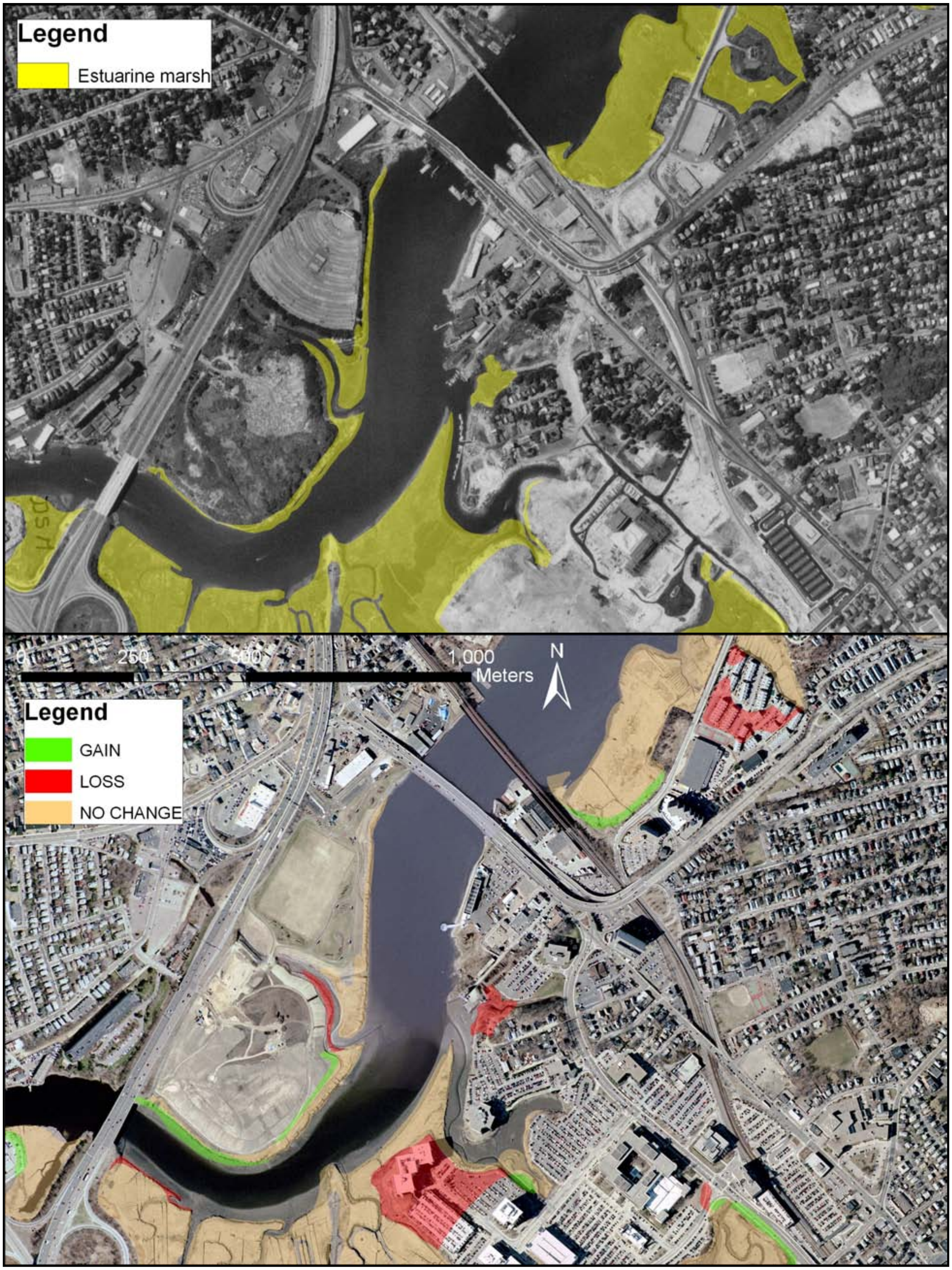

Figure 11. Neponset River, Boston/Quincy: 1971 aerial photograph with mapped estuarine marsh (top) and 2001 aerial photograph showing 1971-1995 trends (bottom).

Trends for Cape Cod

Estuarine marsh trends for Cape Cod are shown in Table 11 and loss categories are graphically depicted in Figure 12. At the turn of the 20th Century, an estimated 19,818 acres of estuarine marsh existed on Cape Cod. By 1952, the acreage dropped by 2,749 acres to total 17,069 acres (86 percent of the 1893 acreage). From 1952 to 1971, Cape Cod's estuarine marsh acreage decreased another 1,500 acres to 15,568 acres (79 percent of 1893 base). By 1995, the salt marsh area fell by 333 acres to 15,235 (77 percent of the 1893 acreage).

Table 11. Estuarine marsh trends for Cape Cod (values in acres; n/a is not available).

Trend	1893 to 1952	1952 to 1971	1971 to 1995
Gain	**4,141.59**	**495.63**	**583.97**
Loss	**-6,890.28**	**-1,995.78**	**-917.85**
Loss to Agriculture	-241.43	-0.52	-0.17
Loss to Developed	-611.00	-143.06	-12.23
Loss to Undeveloped Filled/Drained	-4,259.79	-723.23	-287.38
Loss to Open Water	-1,691.82	-296.60	-207.89
Loss to Other Wetland	-86.24	-832.37	-410.18
Loss Undetermined	0.00	0.00	0.00
No Change	**11,120.59**	**14,978.95**	**14,602.66**
Change in Type	**n/a**	**93.91**	**45.34**
Net Change	**-2,748.69**	**-1,500.15**	**-333.88**

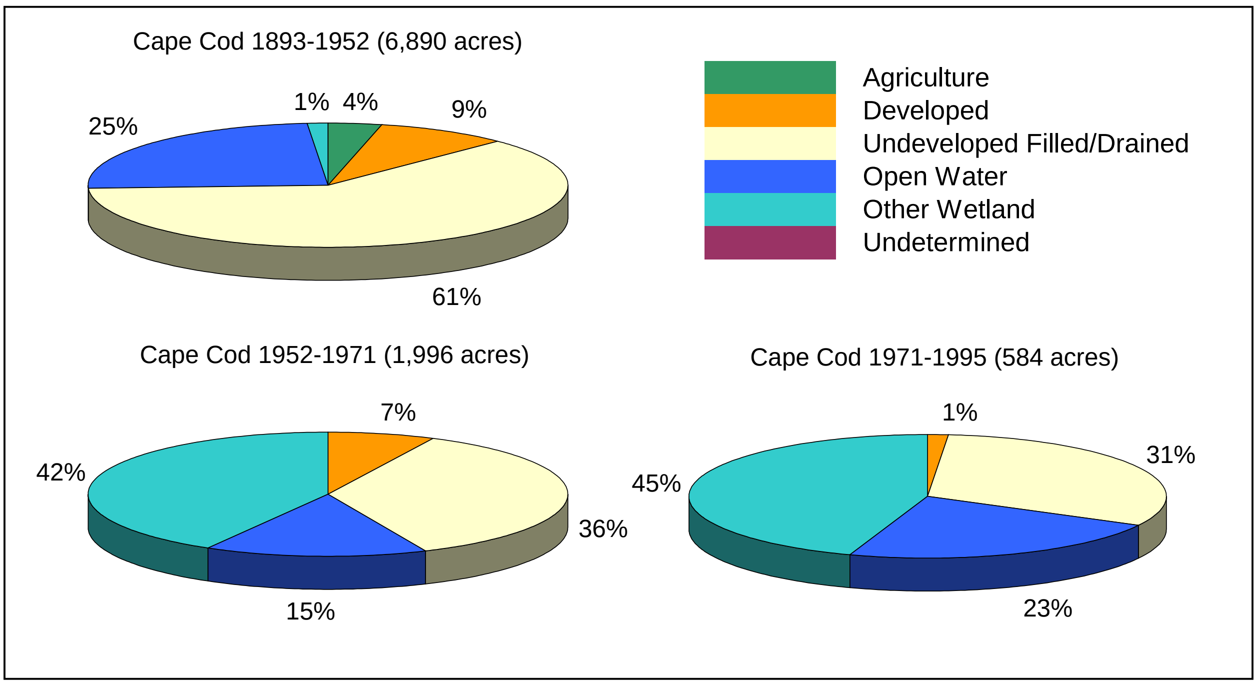

Figure 12. Categories of estuarine marsh loss for Cape Cod.

From 1893 to 1952, losses of estuarine marshes totaled about 6,890 acres. Of the losses, nearly three-quarters were to upland, including agriculture, developed, and undeveloped filled/drained. Twenty-five percent of the losses involved conversion of marsh to open water, with the remainder as conversion to other wetland types, including significant fresh or brackish wetlands. An example of the trends from 1893 to 1952 is shown for the Hyannis Inner Harbor area and Snows Creek area off Lewis Bay in Barnstable in Figure 13. Note the large area of estuarine marsh loss to upland fill and development and conversion to fresh or brackish marsh landward of the road and railroad crossings. Also note the areas of apparent gain, many of which are the product of areas not mapped on the USGS historical maps and, as noted in the Methods section, not adjusted for in the revised estimates of 1893 estuarine marsh.

From 1952 to 1971, losses were nearly 2,000 acres. About 43 percent of the losses were to upland, 15 percent to open water, and 42 percent to other wetlands, including brackish and tidal flats. Meanwhile, the study area had an increase of nearly 500 acres of new estuarine marsh. Overall, Cape Cod experienced a net loss of 1,500 acres. An example of the 1952-1971 estuarine marsh trends in the Parkers River estuary in Yarmouth is portrayed in Figure 14. Note the significant loss of estuarine marsh due to waterfront shoreline development.

Between 1971 and 1995, 918 acres of estuarine marshes were lost and 584 acres were gained for a net loss of 334 acres. Thirty-two percent of the losses were conversion of marsh to upland area, 23 percent to open water, and 45 percent to other wetland types. Figure 15 shows estuarine marsh trends for the southern Nauset Beach area from 1971 to 1995. This is a good example of the losses and gains of marsh to the natural migration of the barrier beach.

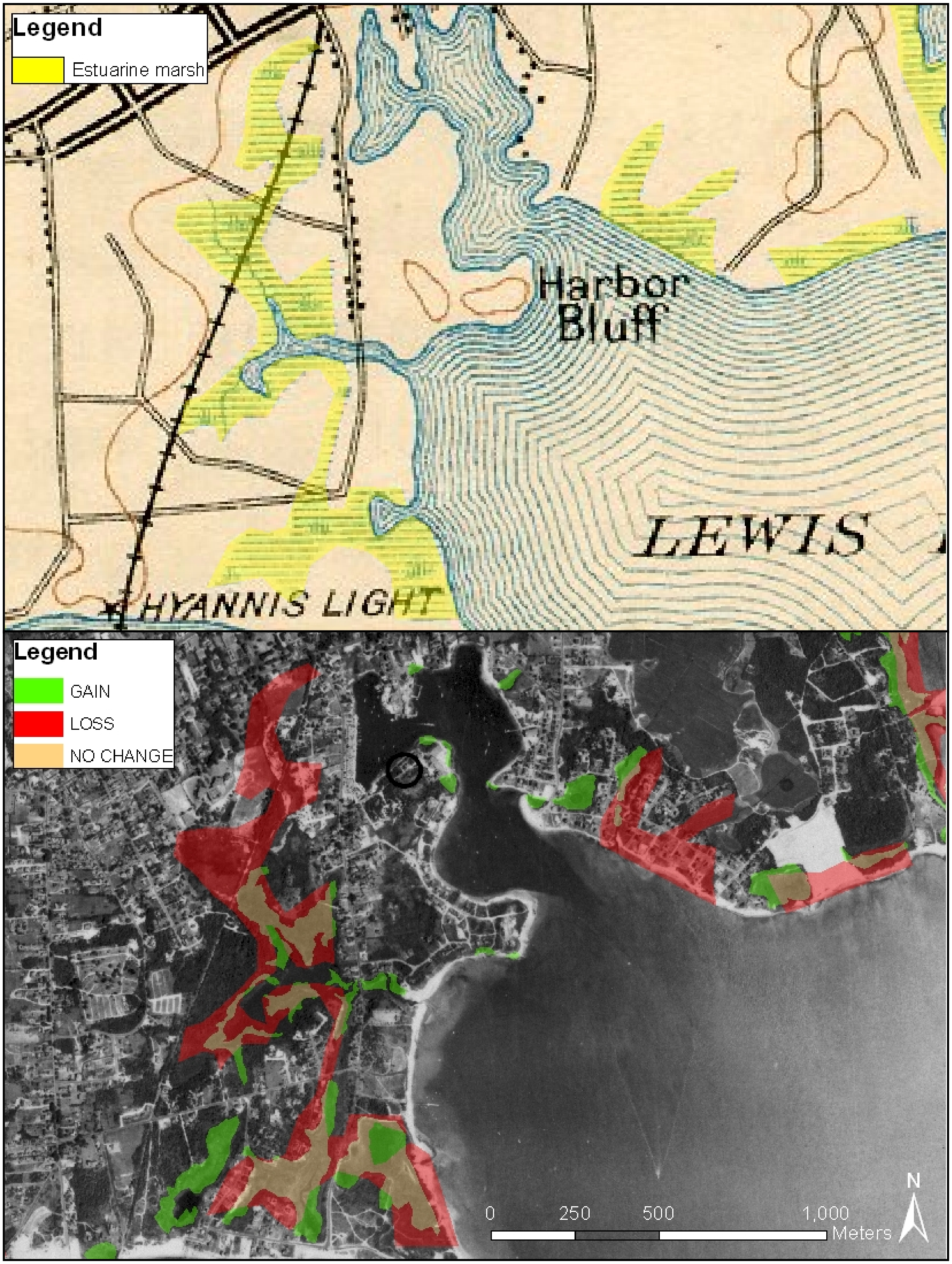

Figure 13. Lewis Bay, Barnstable: 1893 map with mapped estuarine marsh (top) and 1952 aerial photograph showing 1893-1952 trends (bottom).

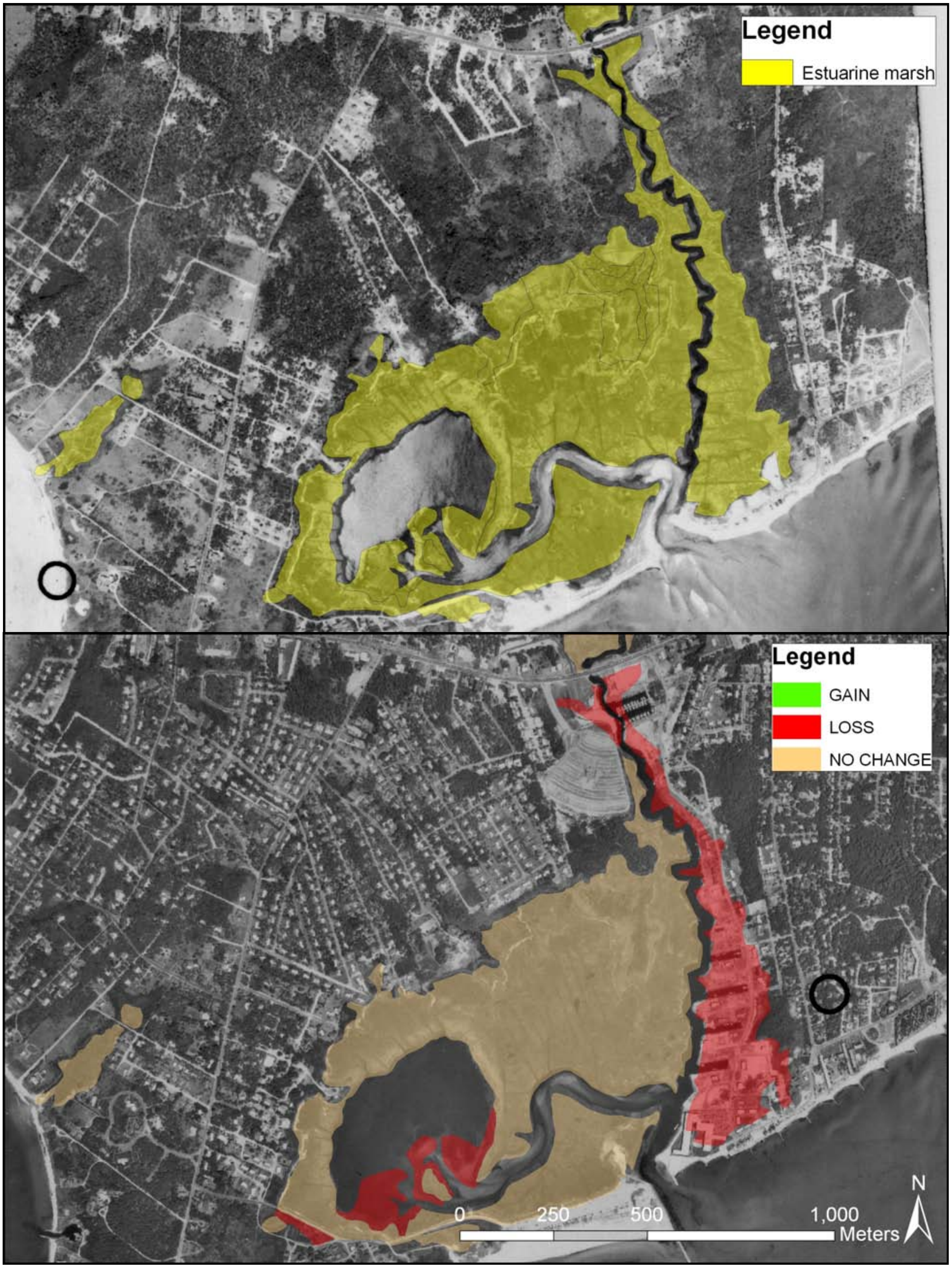

Figure 14. Parkers River, Yarmouth: 1952 aerial photograph with mapped estuarine marsh (top) and 1971 aerial photograph showing 1952-1971 trends (bottom).

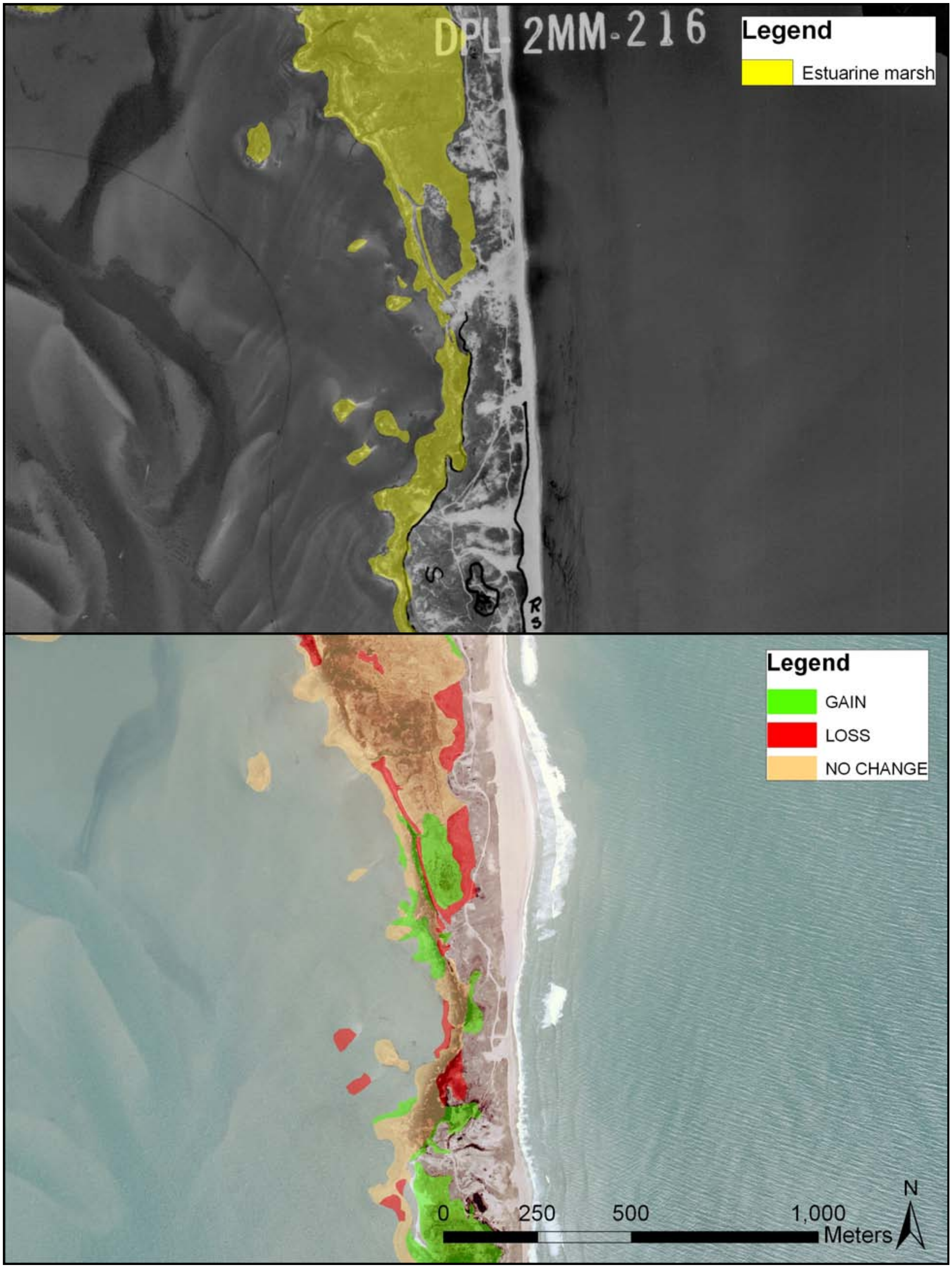

Figure 15. Nauset Beach, Chatham: 1971 aerial photograph with mapped estuarine marsh (top) and 2001 aerial photograph showing 1971-1995 trends (bottom).

Trends for Nantucket, Martha's Vineyard, and the Elizabeth Islands

At the turn of the 20th Century, 2,145 acres of estuarine marsh were estimated to have existed on Nantucket, Martha's Vineyard, and the Elizabeth Islands. By 1952, estuarine marsh acreage was 2,112, and by 1971 estuarine marsh totaled 1,853. Trends over the three time periods are summarized in Table 12, with categories of loss cause identified. Figure 16 shows the loss categories and percentages for the Islands. Most of the loss causes from 1893 to 1952 were not determined because land use data were not available for this area in the 1952 era, and resources were not available to support the photo-interpretation for each loss polygon.

Table 12. Estuarine marsh trends for Nantucket, Martha's Vineyard, and the Elizabeth Islands (values in acres; n/a is not available).

Trend	1893 to 1952	1952 to 1971	1971 to 1995
Gain	**553.01**	**69.87**	**55.30**
Loss	**-585.71**	**-328.28**	**-141.00**
Loss to Agriculture	n/a	-4.01	-1.92
Loss to Developed	n/a	-21.21	-2.67
Loss to Natural Upland	n/a	-172.68	-96.17
Loss to Open Water	-112.94	-71.11	-24.69
Loss to Other Wetland	-1.88	-59.26	-15.54
Loss Undetermined	-470.89	-	-
No Change	**408.97**	**1,741.96**	**1,670.31**
Change in Type	n/a	**41.66**	**42.10**
Net Change	**-32.70**	**-258.41**	**-85.70**

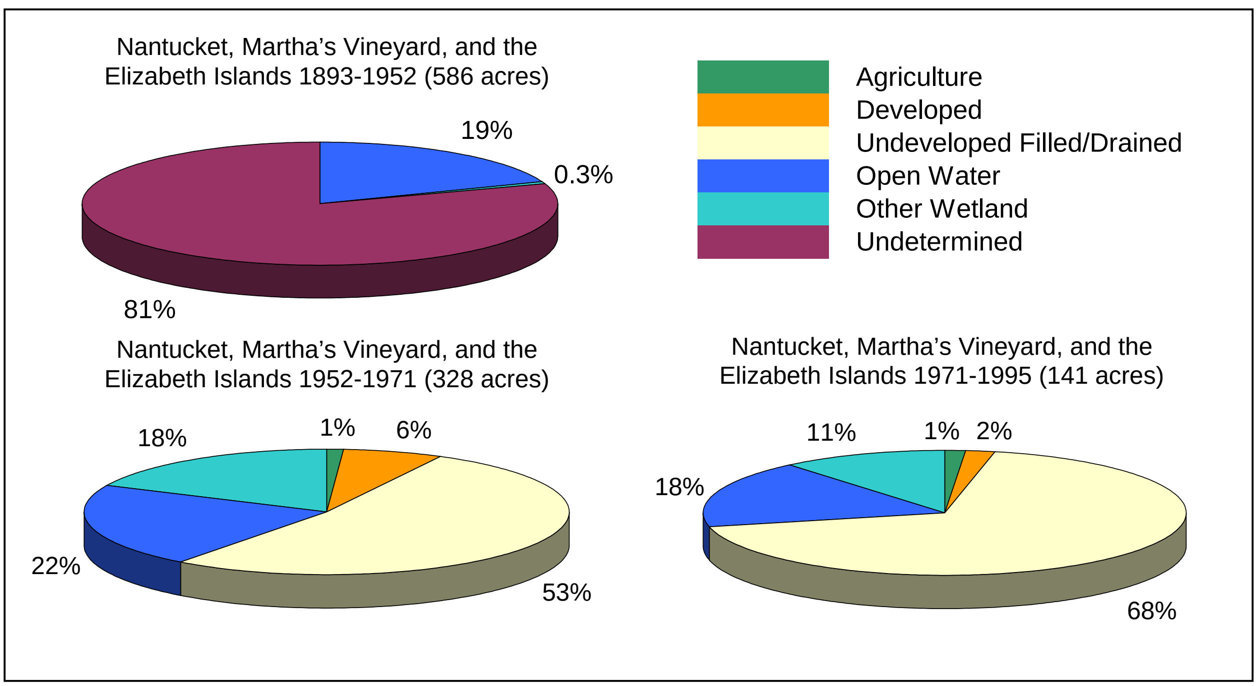

Figure 16. Categories of estuarine marsh loss for Nantucket, Martha's Vineyard, and the Elizabeth Islands.

Between 1893 and 1952, estuarine marsh losses on Nantucket, Martha's Vineyard, and the Elizabeth Islands were 586 acres and gains were 553 acres, for a net loss of 33 acres. Figure 17 illustrates changes from 1893 to 1952 for the area of Quicks Hole Pond on the eastern part of Nashawena Island. Note changes due to apparent closure of pond inlet with subsequent shifts in open water and upland.

From 1952 to 1971, loss of estuarine marsh wetland totaled 328 acres, and gains were 70 acres, for a net loss of 258 acres. Sixty percent of the losses were due to conversion to upland, while 22 percent were attributed to change to open water and 18 percent to conversion to other wetland types. Gains for this period amounted to 70 acres for a net result of 258 acres lost. The status of estuarine marshes and changes from 1952 to 1971 are shown for the Farm Pond area of Oak Bluffs on Martha's Vineyard in Figure 18. Note upland fill as well as the original land use delineations from the 1952 photograph.

More recently, from 1971 to 1995, 141 acres of estuarine marshes were lost, 55 acres were gained, resulting in a net loss of 86 acres. Just over 70 percent of the losses were to upland, 18 percent to open water, and 11 percent were to brackish wetland. Figure 19 shows changes in the Polpis Harbor area of Nantucket where dikes and access roads for residential development restricted or eliminated tidal flows and shifted estuarine marsh to brackish condition.

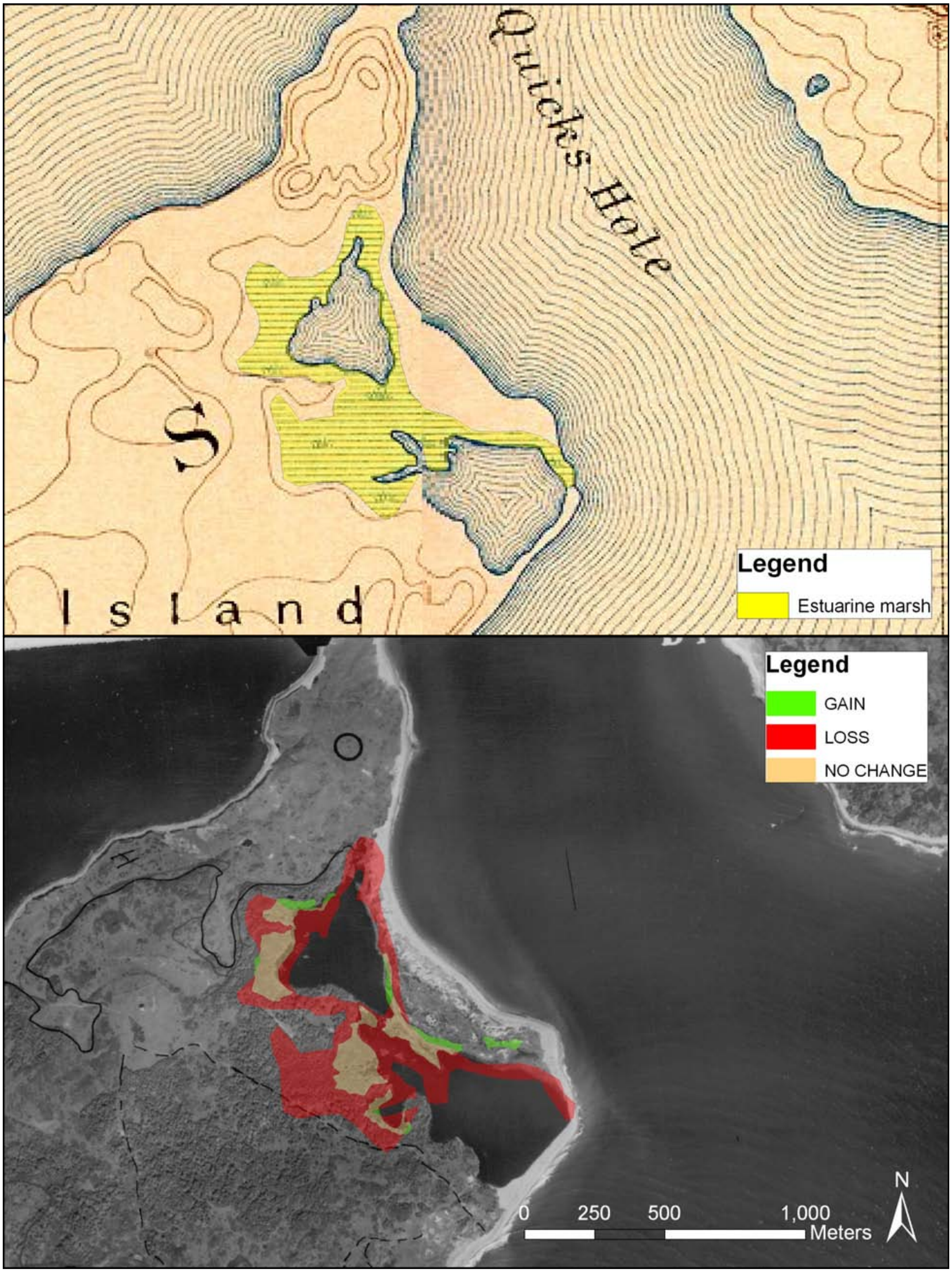

Figure 17. Quicks Hole Pond, Gosnold: 1893 map with mapped estuarine marsh (top) and 1952 aerial photograph showing 1893-1952 trends (bottom).

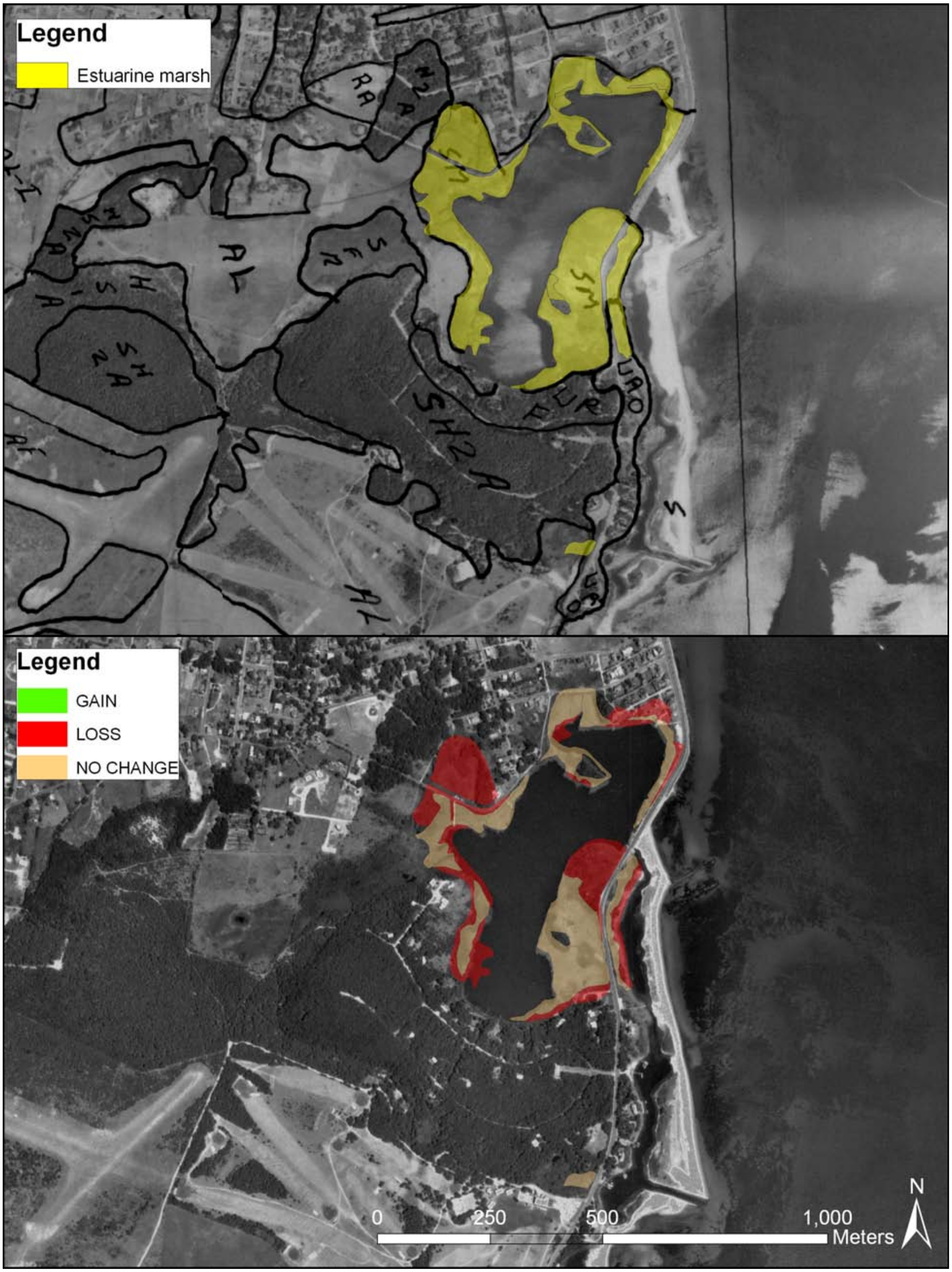

Figure 18. Farm Pond, Oak Bluffs: 1952 aerial photograph with mapped estuarine marsh (top) and 1971 aerial photograph showing 1952-1971 trends (bottom).

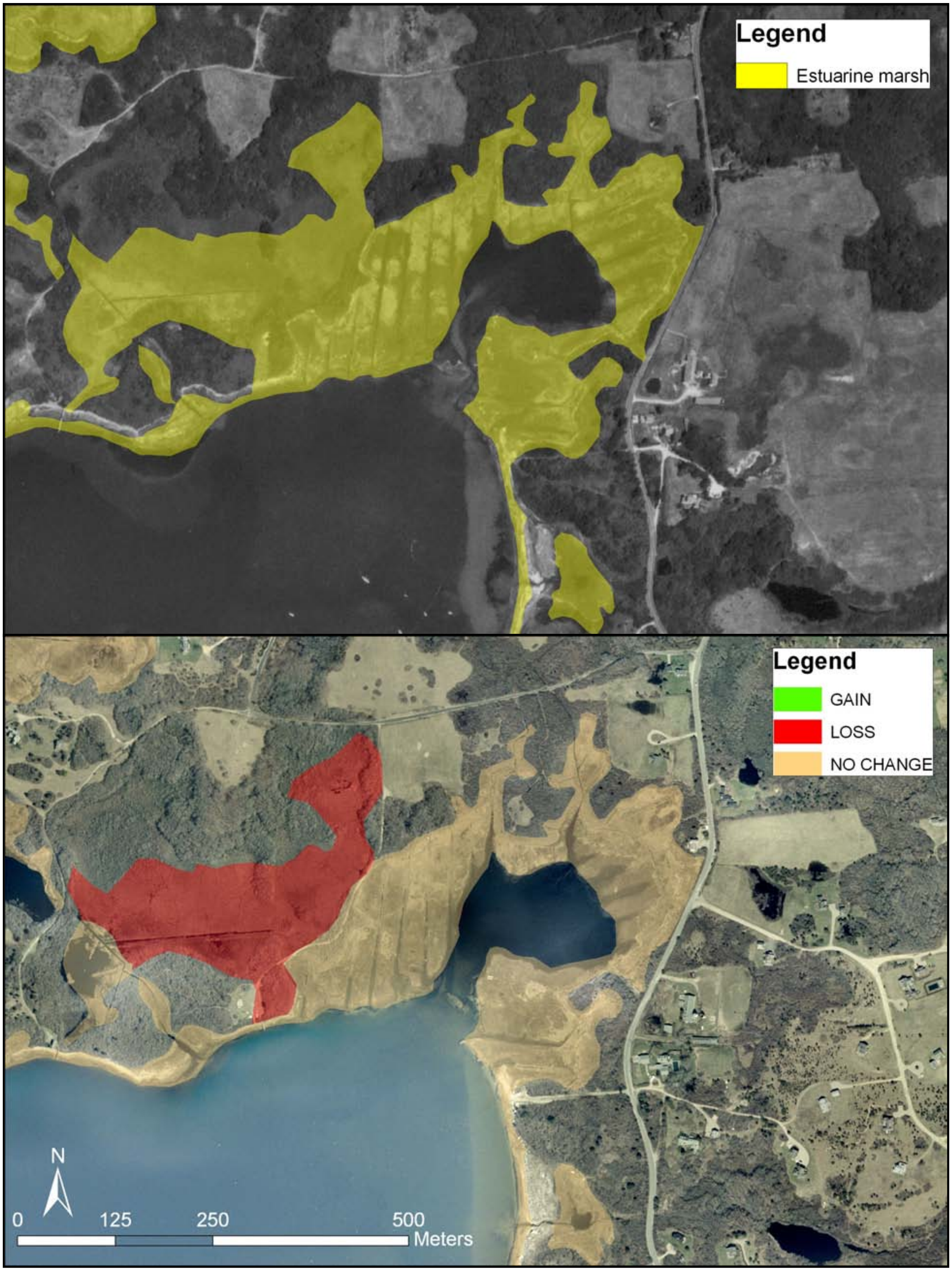

Figure 19. Polpis Harbor, Nantucket: 1971 aerial photograph with mapped estuarine marsh (top) and 2001 aerial photograph showing 1971-1995 trends (bottom).

DISCUSSION

Coastal wetlands trends in Massachusetts have not been well examined. Only a handful of small studies focusing on specific areas have been completed (see Tiner et al. 1998, Tiner and Foulis 1994, and Tiner and Zinni 1988). This investigation is the first in a three-part series that will provide a comprehensive examination of estuarine marsh trends for all of Massachusetts since the late 1800s. The second investigation (currently underway) covers the North Shore, and the last phase will focus on the South Shore and South Coast.

Coastal wetlands in Massachusetts and other New England states have been diked, drained, and filled since Colonial times. The rate of these impacts mirror and directly result from population and land development trends.

Upon arriving on the shores of Massachusetts, Colonial settlers discovered a rich bounty of resources in coastal wetlands that would provide a foundation for the growth of a nation. Salt marshes and associated habitats provided an abundance of fish and game, as well as natural grasslands. The former provided food for Colonial families, while the latter served as lands for livestock grazing and harvesting salt marsh hay. Salt hay provided vital winter fodder that fed livestock through the harsh New England winter. As farmers cleared forests for crops, hay fields, and pastures, demand for and the value of salt marsh hay dropped. Salt marshes then became viewed as sites for "marsh reclamation." Marshes were diked or filled to prevent tidal inundation and to allow farmers to plant upland crops on these fertile soils.

It is important to note that in some areas, especially the Boston Harbor region, a considerable amount of wetland alteration occurred prior to the earliest effective date of this investigation (1893) and therefore actual losses of estuarine marsh will be higher than those documented in this report. Considerable research would have to be done to estimate changes from earlier time periods, including the identification and acquisition of both historic maps and sources of narrative description on estuarine marsh location and extent.

With the industrial revolution, increased population, and expansion of port cities, salt marshes were viewed as new areas for waterfront development. Marshes and tidal flats were filled to create real estate. Boston was the focal point of much of this activity in Massachusetts. Large areas of fill were placed on salt marshes in the Back Bay, South Boston, East Boston, Cambridge, and Charlestown in the mid- to late-1800s. For example, Figure 20 shows an 1852 map (by E.S. Chesbrough, Boston city engineer) and the 1903 USGS topographic map used for this investigation. These images show the widespread filling of the salt marshes of the Back Bay, Fenway, South Bay, Cambridgeport, and west Charlestown.

From 1893 to 1952, the United States became more industrialized, immigration rates climbed, and the population boomed. Consequently, demand for real estate for commercial and residential development increased. Since the many values of wetlands were largely unknown or under-appreciated by the majority of people, filling, diking, and draining of salt marshes continued largely unchecked throughout this period. For the study area that included the already urbanized metro Boston, an estimated 10,500 acres of estuarine marsh were destroyed (for a loss rate of 177 acres per year. When combined with gains of about 5,177, the net loss was 5,288 acres of estuarine marsh (and net rate of loss about 90 acres per year).

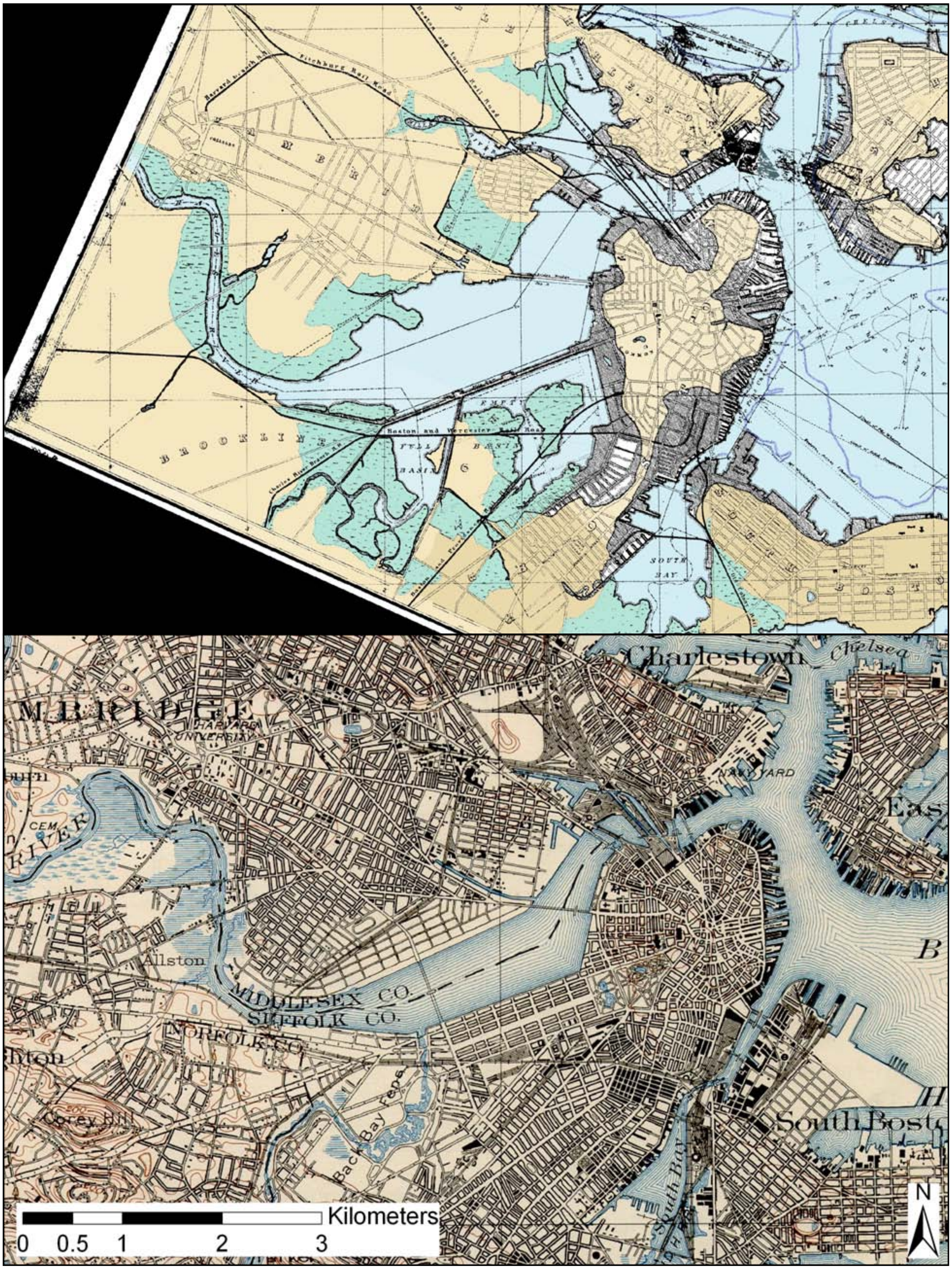

Figure 20. Boston: 1852 map by Chesbrough (top) and 1903 USGS topographic map (bottom).

From 1952 to 1971, the post-War population boom and industrial/commercial growth continued. Facilitated by major investments in transportation infrastructure, residential and commercial development expanded well beyond established urban areas, giving rise to the pattern that is now commonly referred to as "sprawl." Results for this study show that the average rate of loss was identical to the previous period—177 acres per year—and estuarine marsh loss totaled more than 3,300 acres. With the estuarine marsh gains factored in, the net loss was 2,539 acres and the net loss rate was 43 acres per year During this time, Massachusetts became the first state in the nation to adopt wetland protection legislation and regulations with the passage of the Jones Act in 1963.

Development pressures along coastal shores continued from 1971 to 1995 and remain strong today with high demand for waterfront properties in coastal communities. Yet, the values of wetlands also became better appreciated, and the federal government and many states began taking a stronger position in protecting wetlands. For Massachusetts, the Jones Act and the Hatch Act (passed in 1968 to protect inland wetlands) were combined and revised into the Wetlands Protection Act in 1972. In that year, the U.S. Congress passed the Clean Water Act with provisions to regulate the discharge of fill material to most wetlands. In addition, through land conservation efforts, large areas of estuarine marsh and their surrounding habitats have been protected as refuges, wildlife management areas, parks, and nature preserves. The reduction of estuarine marsh loss rates in the 1971 to 1995 period to about 52 acres a year (with net loss rates at 8 acres per year) for a total of 1,255 acres lost (with net loss at 458 acres) points to some success of the contemporary regulatory and conservation programs.

Despite these successes, the legacy of past impacts cannot be ignored. As a complement to environmental protection and conservation measures, restoration serves as a valuable tool for natural resource management. Since the early 1990s, environmental restoration has received elevated attention and resources, as scientists and managers have recognized its value in achieving management goals. In Massachusetts, CZM's Wetlands Restoration Program works with a broad network of partners to develop regional restoration plans, identify and evaluate specific restoration opportunities, implement projects, monitor restoration progress, and deliver outreach and educational resources. To date, more than 46 wetlands restoration projects have been completed, with about 535 acres of wetlands under restoration. The trends information generated from this study supports efforts to identify future restoration sites by locating areas of former estuarine marshes that have been filled, drained, or converted to other wetland types. Information on the historical condition and location of these sites helps to evaluate a potential project's feasibility.

Through this study, baseline information on the spatial and temporal extent of estuarine marshes over four points in time (spanning over 100 years) was developed for approximately one-third of the Massachusetts coast. With the completion of the next two phases, a comprehensive state-wide account of this critical habitat will have been established. Information from this effort directly supports the development of various types of resource condition reports (e.g., State of the Environment, State of the Coast); it offers important perspective in setting goals for wetlands protection, restoration, and conservation; and it provides context for regulatory and restoration decisions. Finally, with a baseline established, the systematic evaluation of estuarine marsh status and trends from 1995 forward becomes much easier, and the information developed can be examined within the background of the trends to date.

CONCLUSION

While it is generally accepted that from early settlement and Colonial times through most of the 20th Century, human development and activities have resulted in the diking, draining, and filling of coastal wetlands in Massachusetts, there have only been a few studies of limited areas documenting the trends of these critical resources. This investigation is the first of a three-part series designed to provide a comprehensive examination of estuarine marsh trends for all of Massachusetts since the late 1800s.

The Massachusetts Office of Coastal Zone Management, the U.S. Fish and Wildlife Service, and the University of Massachusetts Department of Plant, Soil, and Insect Sciences examined the trends of estuarine marshes in Boston Harbor, Cape Cod, Nantucket, Martha's Vineyard, and the Elizabeth Islands over four points in time: 1893, 1952, 1971, and 1995. Using digital aerial photographs and maps, photo interpreters mapped estuarine marshes for each effective date and identified changes that occurred in the period between each date.

The study was limited by a number of factors including the accuracy of the data presented on the historical topographic maps, the quality of the 1952 and 1971 aerial photographic images, scales and alignments of both the source photographs and maps and the data generated from the sources, and the use of on-screen interpretation (as compared to stereoscopic). Because the 1893 era maps were found to have missed significant estuarine area, investigators accounted for omissions, mis-classifications, human-induced and natural gains as best they could to generate an estimate of the estuarine marsh area circa 1893. The estimated values are used throughout the report.

The results demonstrate that for the entire time period covered by the investigation, the net change of estuarine marsh was severe: 30 percent of the resource present in 1893 was lost by 1995. This figure would be significantly higher without the large gains of naturally forming marsh that occurred (of which a good part was aided by human activities such as the creation of breakwaters and the filling and development of open water). It is also important to note that significant losses took place prior the earliest time point of this study—large areas of salt marsh and inter-tidal flats were filled in metro Boston in the mid- to late-1800s, including the Back Bay, South Boston, East Boston, Cambridge, and Charlestown.

Results also show that the extent and rate of the impacts to estuarine marshes relate to population growth, land development trends, and regulatory protection. The period from 1893 to 1952 witnessed the greatest losses, with a net loss figure of 5,288 acres of estuarine marsh and a net rate of 90 acres lost per year. This period saw dramatic increases in industry and technology, high immigration rates, and a rapidly increasing population. Demand for real estate for commercial and residential development was strong and the filling, diking, and draining of salt marshes went largely unchecked.

Net losses from 1952 to 1971 totaled 2,539 acres, with net loss rate at 43 acres per year. During this period, demand for areas to support commercial and residential development continued to be strong and regulatory protection was limited.

During the last period of the investigation, from 1971 to 1995, net losses of estuarine marsh were curtailed, totaling 458 acres or 8 acres per year. Declining losses correspond with the establishment of wetlands regulatory protection programs, and losses that still occurred were offset in some part by natural gains.

Prior to this study, very limited information was available on the trends of coastal wetlands. The documentation and reporting on estuarine marsh trends in Massachusetts serve many valuable functions, including the development of various types of resource condition reports; restoration site identification and evaluation; effectiveness assessment of regulatory programs; setting habitat area goals for protection, restoration, and conservation; and providing context for current regulatory and restoration decisions.

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