

2009

Hampton-Seabrook Estuary Habitat Restoration Compendium

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Hampton-Seabrook Estuary Habitat Restoration Compendium



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This project was funded by the

NOAA Restoration Center

in conjunction with the

**Coastal Zone Management Act by NOAA's Office of Ocean and Coastal Resource
Management in conjunction with the New Hampshire Coastal Program**

and

**US Environmental Protection Agency's National Estuary Program through an
agreement with the University of New Hampshire**



Acknowledgements

We would like to thank the following people whose contributions and knowledge helped to improve this project greatly.

Michael Dionne – NH Fish and Game
Hunt Durey – MA Office of Coastal Zone Management
Sue Foote – Seabrook Conservation Commission
Steve Gaughan – NH Department of Environmental Services
Joanne Glode – The Nature Conservancy
Ellen Goethel – Hampton Conservation Commission
Pamela Hunt – NH Audubon Society
Eric Hutchins – NOAA Restoration Center
Don Kierstead – USDA Natural Resources Conservation Service
Duncan Mellor – Waterfront Engineers LLC
Betty Moore – Hampton Historical Society
Bill Nichols – NH Natural Heritage Bureau
Jay Odell – The Nature Conservancy
Cheri Patterson – NH Fish and Game
Michelle Rowden – Salisbury Conservation Commission
Fay Rubin – University of New Hampshire
Dan Sperduto – NH Natural Heritage Bureau
Thelma Thompson – University of New Hampshire
Peter Tilton – Defiant Lobster Co.
Larry Ward – University of New Hampshire

Also many thanks to the advisory committee to this project for their insights:

Ted Diers - NH Coastal Program
Jennifer Hunter - Piscataqua Region Estuaries Partnership
Ray Konisky - The Nature Conservancy
Beth Lambert - formerly of the NH Coastal Program
Kevin Lucey - NH Coastal Program
Derek Sowers - Piscataqua Region Estuaries Partnership
Phil Trowbridge – Piscataqua Region Estuaries Partnership

Cite as: Eberhardt, A.L. and D.M. Burdick. 2009. Hampton-Seabrook Estuary Habitat Restoration Compendium. Report to the Piscataqua Region Estuaries Partnership and the New Hampshire Coastal Program, Durham and Portsmouth, NH.

Cover map: DesBarres, J.F.W. 1776. The Atlantic Neptune. HNS101. Courtesy of the National Maritime Museum, Greenwich, U.K.

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Introduction

The Hampton-Seabrook Estuary Habitat Restoration Compendium (HSEHRC) is a compilation of information on the historic and current distributions of salt marsh and sand dune habitats and diadromous fishes within the Hampton-Seabrook Estuary watershed. These habitats and species groups were selected due to the important ecological role they play within the watershed and with effective restoration and conservation efforts, will continue to play. Other ecologically important habitats and species, such as avifauna, shellfish and eelgrass beds, currently are or historically were present within the watershed. Shellfish and seagrass are recognized as important habitats within the Estuary, but were not included in the current report because a different analytical approach may be required for such dynamic and/or short-lived species. A recent report by the New Hampshire (NH) Audubon Society details modern bird use of the Hampton-Seabrook Estuary (McKinley and Hunt 2008).

Restoration opportunities have been identified within the watershed by evaluating habitat loss and changes in land use over time. Restoration opportunities are not prioritized in order to allow the goals and objectives of each restoration practitioner to govern project selection. However, in accordance with an ecosystem-based approach to restoration, areas containing multi-habitat restoration opportunities are considered to be of the highest priority. Furthermore, restoration efforts should ensure processes critical for the support of restored components are maintained or reestablished.

The goal of this report is to identify restoration opportunities within the watershed derived from data on habitat change. Many other factors exist that are important in the identification and selection of restoration projects, including water quality and non-point source pollution, water withdrawal, harbor maintenance, recreational impacts, human history, and socioeconomic factors, among others. Although information regarding these factors is not explicitly included in this analysis, these factors must be considered and addressed as they may limit the potential for success in specific restoration efforts

We present a series of maps detailing changes in the extent of sand dune and salt marsh habitats over time, the current and historic distribution of seven diadromous fish species, and restoration opportunities within the Hampton-Seabrook Estuary and watershed. A narrative describes the methods used, the results of analyses and examples of prominent restoration projects. Each major section concludes with references used in the narrative and maps. The maps are available for viewing as portable document format (.pdf) files. For those with GIS capabilities, the ArcMap 9.2 project files, associated data files and metadata are included on the compact disc as well. The underlying concept and methods for the HSEHRC stem from a previous project conducted within the Great Bay Estuary, the Great Bay Estuary Restoration Compendium (Odell et al. 2006).

Project Area

The Hampton-Seabrook Estuary (Figure 1) is a shallow, tidally dominated, barrier beach system. The watershed encompasses 47 square miles and includes the towns of Hampton, Hampton Falls, North Hampton, Stratham, Seabrook, Exeter, and Kensington, NH and Salisbury, MA. The Estuary receives freshwater inputs from Tide Mill Creek to the north, the Taylor and Hampton Falls Rivers from the northwest, Brown's River and Cain's Brook from the west, and the Blackwater and Little Rivers from the south. Unlike the Great Bay Estuary, the Hampton Seabrook Estuary is dominated by salt marsh habitat. In fact, the Estuary contains over 1800 hectares (4000 acres) of tidal marsh. In addition, the Estuary supports many other important coastal habitats including the most productive softshell clam beds in the state, important roosting, feeding and nesting grounds for shorebirds and saltmarsh sparrows, as well as remnant sand dunes. As a result of the important ecological services provided by the Hampton-Seabrook Estuary, it was listed as a conservation focus area in The Nature Conservancy's Land Conservation Plan for New Hampshire's Coastal Watersheds (Zankel et al. 2006).

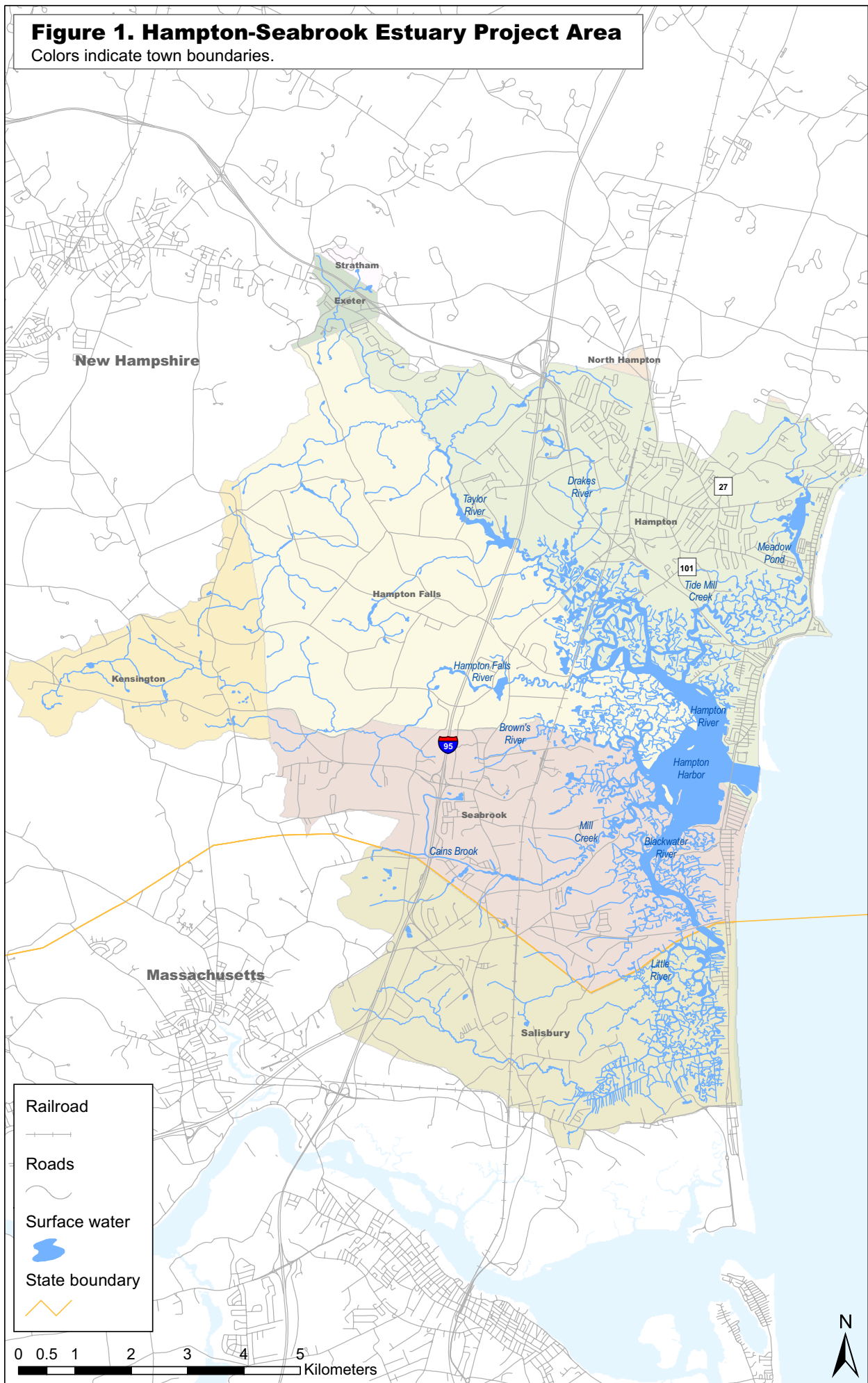
The history of land use in the Hampton-Seabrook Estuary dates back at least 4000 years to Native American settlements. From the few remnants of these settlements that remain, it is clear that Native Americans relied on the Estuary for its rich finfish and shellfish resources. In the early 17th century, European settlers were attracted to the Hampton-Seabrook Estuary by the large expanse of saltwater marsh. Salt marsh hay (*Spartina patens*) was considered a valuable food source for livestock. Salt hay could be harvested relatively easily and at a low cost due to the fact that expensive manure and fencing was not needed. In fact, it was considered so valuable that each of the settlers of Hampton received an expanse of salt marsh in their land grant so that they could take advantage of the salt hay. In addition to nourishing livestock, the extensive marshlands provided abundant food resources for colonial settlers including shellfish, finfish and waterfowl.

Although the European settlers highly valued the salt marsh, their use of it was not without impacts. Heavy pasture use resulted in the high density of ditching that is still seen in the marsh today. By cutting ditches to drain the marsh, it was thought to sustain the abundance and improve the quality of the salt hay as well as increase the abundance of black grass (*Juncus gerardii*), another valuable marsh grass used as feed. Salt pannes were reduced in these systems not only by cutting ditches to connect them to the drainage network, but also because the dredge spoil from ditching was deposited in the salt pannes to reclaim them as high marsh.

Along with exploiting the marshlands for food, the early settlers constructed sawmills, windmills, grist and fulling mills along the rivers and creeks of the Hampton-Seabrook Estuary, the first of which was built as early as 1640. Dams were erected to harness the energy needed to drive these mills, and in so doing, resident and migratory fish movement throughout the stream network became impeded.

Figure 1. Hampton-Seabrook Estuary Project Area

Colors indicate town boundaries.



Over time, salt hay farming declined as uplands were cleared of forests and farming methods became more efficient and cost effective. By the early 1900s, salt hay farming ceased in the Hampton-Seabrook Estuary and the marsh was no longer perceived as valuable. Development of salt marsh for commercial and residential interests quickly followed. By 1930, the majority of Hampton Beach was developed, resulting in the destruction of both marsh and dune habitats. As the area developed into a popular summer resort, the abundance of mosquitoes produced in the marshes became a problem that needed to be addressed. In the late 1930s additional ditches were cut into the marsh to drain it of potential mosquito breeding habitat, further altering the marsh drainage patterns, vegetation and density of pannes. Unfortunately, the small fish that preyed on the mosquitoes lost their habitat as well.

Historically, the shoreline of the Hampton-Seabrook Estuary was quite dynamic (Figure 2). The rapid development of the dunes and marshes, as well as the construction of the mile-long bridge at the turn of the 19th century, served to harden and decrease the dynamic nature of the shoreline. The jetties along either side of the inlet, installed in 1930, further decreased shoreline movement. As the narrow channel connecting the Estuary to the ocean filled with sediment, it required dredging, first conducted in 1965, to maintain a navigable inlet. The inlet is currently maintained by the U.S. Army Corps of Engineers and due to the high rates of sediment transport and deposition within and around the channel, maintenance dredging is required approximately every 5 years.

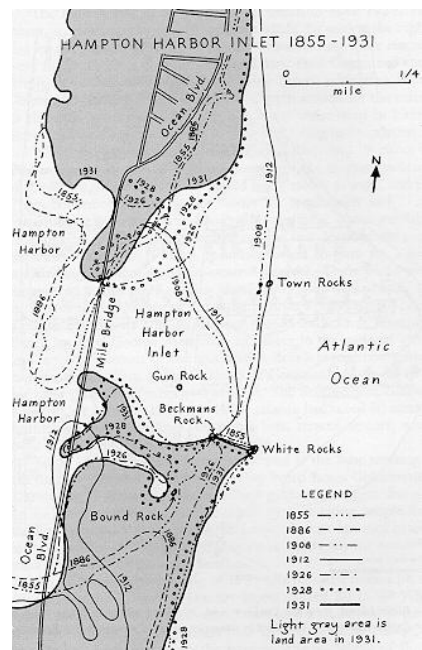


Figure 2. Hampton River inlet change, 1855-1931.
Map by Alex Wallach, in Randall 1989.

Restoration potential in the Hampton-Seabrook Estuary watershed

While there is a rich history of impacts to the Hampton-Seabrook Estuary, it does not preclude the potential for a well functioning ecosystem. Restoration of a developed estuary presents many challenges, including property ownership, current land uses, high occurrence of invasive species, and persistent impacts, among others. However, this does not reduce restoration potential in the watershed; rather, it calls for a strategic approach to restoration viewed at a landscape level. Restoration projects should be viewed not only as the discrete project area, but also in terms of the processes provided by the surrounding landscape. As a result, restoration projects may not only require restoration of physical habitats but also modifications to surrounding land and water uses (e.g., stormwater control, wastewater treatment discharge into the estuary). Further, coastal systems are dynamic. An ecosystem-based approach requires the understanding that some natural and human-caused changes are inevitable, and therefore, an adaptive and flexible approach to managing estuarine and watershed resources as well as specific restoration projects is needed for success.

Many areas of intact, well functioning habitat exist within the watershed; conservation is an important approach in protecting these areas from future impacts to maintain ecological functions. An important component to any successful restoration or conservation effort, particularly in a developed estuary, is to build community understanding and support; therefore, education and outreach efforts should also be a component of restoration efforts. Another important component is understanding the results of restoration actions through monitoring. Improved understanding of management actions could identify successful as well as failing projects (to get them back on track) and inform future projects. Monitoring protocols have been developed for various salt marsh restoration approaches (http://marine.unh.edu/jel/tidalmarsh_ecology/gpacregionalstandards.pdf) and dam removal (<http://www.gulfofmaine.org/streambarrierremoval/>), and could be modified for monitoring dune restoration.

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Salt marshes



Postcard credit: Hampton Historical Society

Salt marsh overview

From Odell et al. 2006

Salt marshes are intertidal wetlands typically located in low energy environments such as estuaries. They exist both as expansive meadow marshes and as narrow fringing marshes along shorelines. Salt marshes are considered one of the most productive ecosystems in the world due to high rates of plant growth. Numerous ecological functions are provided by salt marshes, including shoreline stabilization, wildlife habitat, and nutrient cycling. They also serve as important breeding, refuge and forage habitats for many species of crustaceans and other invertebrates, fish and birds. These organisms help to export nutrients and energy from salt marshes to support coastal food webs through their regular movements from salt marshes into other estuarine and marine habitats.

In the past few centuries, much of the salt marsh habitat in New England has been altered or destroyed. Historically, salt marshes were first ditched and drained for salt marsh hay farms and later for mosquito control. Furthermore, coastal development for roadways, homes, and industry resulted in extensive dredging and filling of salt marshes. As human understanding of salt marsh functions has improved, efforts have increased to conserve and restore these habitats. Although wetland regulations have reduced many impacts, salt marshes continue to be degraded and destroyed as coastal development persists. Salt marshes are a scarce habitat type, occupying only about 0.1% of the land area of New Hampshire.

Current threats to salt marshes include reduced tidal flow due to undersized culverts under roadways and train beds, loss of the upland buffer due to coastal

development, excess nutrient inputs from stormwater runoff, and colonization by invasive species. The New Hampshire Coastal Program and others have led efforts to abate the threats to NH salt marsh persistence through conservation and restoration projects. Recent salt marsh restoration projects in the Hampton-Seabrook Estuary include Brown's River in Seabrook, Landing Road in Hampton, and Cains Brook in Seabrook.

Salt marsh impacts and restoration methods

Adapted from Odell et al. 2006

Hydrologic Restoration

Construction of transportation corridors over marshes often filled them directly, but also reduced or eliminated tidal flow to the upstream areas. Also, agricultural activities sometimes diked and drained marshes to convert them to fresh pasture. As a result of tidal restrictions, many areas that were healthy marshes are now deteriorating and are not providing important functions such as fish production. To restore the health and function of restricted marshes, culverts large enough to support flow of the full tidal range can be placed through the corridors at old or current creek locations. In 1994, the U.S.D.A. Natural Resources Conservation Service (NRCS), then the Soil Conservation Service (SCS), developed an atlas of marsh restrictions and tentative solutions for sites covering over 1,200 acres in the state (20% of New Hampshire's remaining salt marshes). By 2006, just 12 years after the NRCS atlas was produced, adequate tidal flow has been restored to most of the sites.

Hydrologic restoration can be an extremely effective method of restoring salt marshes because it addresses overall marsh function. Tidal restrictions prevent the natural processes of tidal flooding, which serve to maintain surface elevation with respect to sea level. Cut off from the tides, marshes often lose surface elevation rather than gain it, and since rates of sea level rise are predicted to increase, it is imperative that we foster marsh building by restoring tidal hydrology. Response to restoration is often very rapid and includes increased saltwater and sediment inputs, increases in salt marsh vegetation, and decreases in invasive plant species. Furthermore, the method requires little maintenance. However, hydrologic restoration of salt marshes is often expensive and requires a great deal of time to plan, design and coordinate. Hydrologic analyses must be conducted to ensure that restoration of the tidal regime does not create flooding conflicts with adjacent land uses.

Excavation of Fill

Marshes have been filled by coastal development and disposal of dredge spoil. Most of the filled marsh in the Hampton-Seabrook Estuary is associated with transportation corridors (roads and railroads) and residential and commercial development. Infrastructure and recreational resources prevent fill removal at most sites in the Estuary (e.g., development along Hampton Beach), but the potential does exist at some sites (e.g., parking lot off Northern Blvd. in Salisbury, railroad berm along western section of salt marsh in Hampton and Hampton Falls).

Excavation is effective for lowering the elevation of marshes to ensure adequate tidal inundation. It is also an effective method for removing invasive species such as the exotic variety of common reed (*Phragmites australis*). Excavation requires the use of heavy earth moving equipment as well as a suitable location for the disposal of dredge spoil.

Open Marsh Water Management (OMWM)

Two periods of ditching salt marshes have caused most of our larger marshes to be unnaturally drained. From European settlement until about 100 years ago, ditches were created in marshes to facilitate harvest and enhance the growth of salt hay. Beginning in the 1930s, new knowledge that mosquitoes could carry disease and the onset of the Great Depression combined to send crews of previously unemployed men to ditch the marshes. With regard to mosquito control, the ditching was a failure – mosquitoes still bred in small water pockets and their main predators (small fish) were effectively eliminated from the marsh surface by the drainage ditches. Although the precise effects of the ditches are not clear, there has been some effort to reverse the drainage of the marsh surface. Such projects plug ditches using the spoil from the excavation of small ponds. These efforts may result in more habitat for small fish. However, OMWM efforts impact only small areas of marsh and the hydrologic effects are quite localized. OMWM requires heavy machinery and may require periodic maintenance. Furthermore, the ecological impacts of OMWM appear to be mixed and are currently not fully understood. Experimental research is needed, not only to better understand the impacts of OMWM on marsh hydrology and function, but also to explore alternative approaches to restoring and managing ditches.

Invasive Plant Removal

A variety of factors including reduced tidal flow, filling and disturbing marsh edges, and increased stormwater runoff have resulted in the colonization of salt marshes in New Hampshire by invasive, exotic species such as common reed and purple loosestrife (*Lythrum salicaria*). Just arrived from Massachusetts is a new plant invader from Asia, perennial pepperweed (*Lepidium latifolium*), which has been found colonizing upper marsh edges in the Estuary. Multiple methods have been developed to remove invasive species and restore salt marsh vegetation with varying degrees of success. Guidance from the Coastal Watershed Invasive Plant Partnership (CWIPP: <http://des.nh.gov/organization/divisions/water/wmb/coastal/cwipp/>) for species-specific treatments is recommended.

Mowing is effective at reducing invasive plant biomass and can increase sunlight available to competing native species, but the dense stands of the invasive plants return in one to two years. Mowing is labor intensive and typically requires annual cutbacks with heavy machinery. Mowed clippings and dredge spoil must be properly disposed of to prevent growth of invasive species elsewhere. Due to low success rates, mowing is often used in combination with other invasive plant removal methods.

Burning is an efficient removal method for large areas of invasive plants and increasing soil nutrients. Because the prior year's plant material is needed to serve as fuel, burning can only occur every other year. Opportunities for burning are also limited by condition requirements for season, precipitation, and wind. Burning does not eliminate the perennial invasive plants, and colonization by other invasive plants is encouraged; therefore, burning is often used in conjunction with other methods.

Application of herbicide to invasive vegetation in salt marshes can effectively decrease invasive growth to allow native plants to establish. Herbicide can be used over a large area or can be applied as a spot treatment in areas where desirable vegetation exists. However, glyphosate, the most widely used herbicide, is a broad-spectrum herbicide that will kill all vegetation it contacts. Although glyphosate biodegrades quickly, it and the chemicals used to aid its uptake (surfactants) can affect aquatic organisms. Furthermore, multiple applications of herbicide are required. The success of each application is dependent on the plant growth stage, so initial applications have been found to be most effective during short periods in late summer (though recent evidence shows early application to be equally effective). Herbicide is most effective when sprayed several weeks after cutting or mowing. Control for each species of invader needs to be specific and applied rigorously using different techniques over the course of the growing season for several years.

In order to facilitate colonization by salt marsh vegetation following removal of invasive species, seeds, bare root seedlings, or plugs of native salt marsh vegetation can be planted. Although labor intensive, planting efforts can be effective at establishing native vegetation that will outcompete invasive species. Furthermore, planting efforts provide opportunities for community involvement.

Erosion controls

Salt marshes exist as a dynamic balance between erosion and marsh building. When erosion exceeds marsh building, marsh loss occurs. The placement of semi-permeable barriers seaward of salt marsh edges can reduce exposure and aid sediment accretion by reducing re-suspension of sediments. Erosion control devices are cost effective, easily constructed, and biodegradable; however, they often require maintenance and annual reconstruction following winter ice damage.

Conservation

It is estimated that sea level will rise a minimum of two feet within the next 100 years (Ward and Adams 2001). Salt marshes play a critical role in adapting to sea level rise. As tidal inundation increases with the rising seas, the upland edges of salt marshes will convert to new marsh given adequate sediment inputs. Therefore, where the upland is undeveloped, salt marshes will migrate landward with the increase in tidal flooding and continue to serve as a buffer between the terrestrial and marine environments. However, in areas where buildings, roadways, bulkheads, and other structures exist along the

upland edge, the landward movement of salt marsh cannot occur. By prohibiting the landward migration of salt marshes, coastal development can result in marsh loss and increased coastal flooding.

The high level of development in low-lying areas within the Hampton-Seabrook Estuary renders many areas vulnerable to increased coastal flooding as sea level rises. In fact, a 2001 study of coastal flooding in New Hampshire found that an additional 550 acres of non-marsh land could be subject to flooding in Hampton and Seabrook with a two foot sea level rise (Figures 3 and 4; Ward and Adams 2001). As areas of undeveloped upland allow for natural marsh expansion, they play an important role in the protection of coastal communities with sea level rise. As a result, conservation of both existing salt marsh as well as undeveloped uplands is an important tool in combating sea level rise.

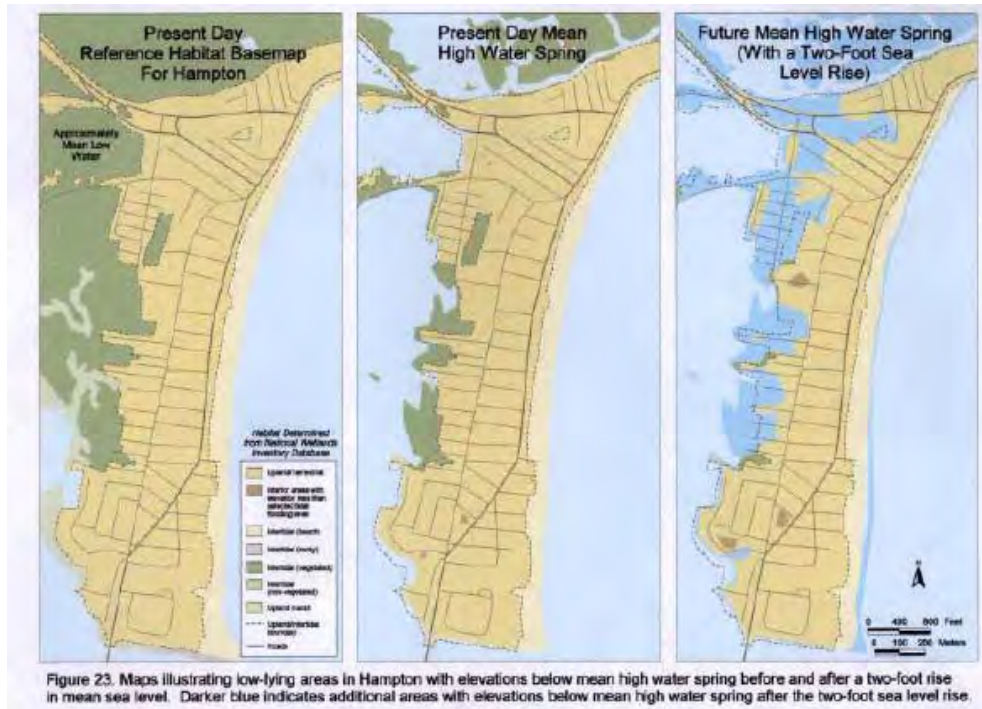


Figure 23. Maps illustrating low-lying areas in Hampton with elevations below mean high water spring before and after a two-foot rise in mean sea level. Darker blue indicates additional areas with elevations below mean high water spring after the two-foot sea level rise.

Figure 3. Increases in the areas flooded in Hampton, NH with a two foot increase in tidal height due to sea level rise. From Ward and Adams (2001).

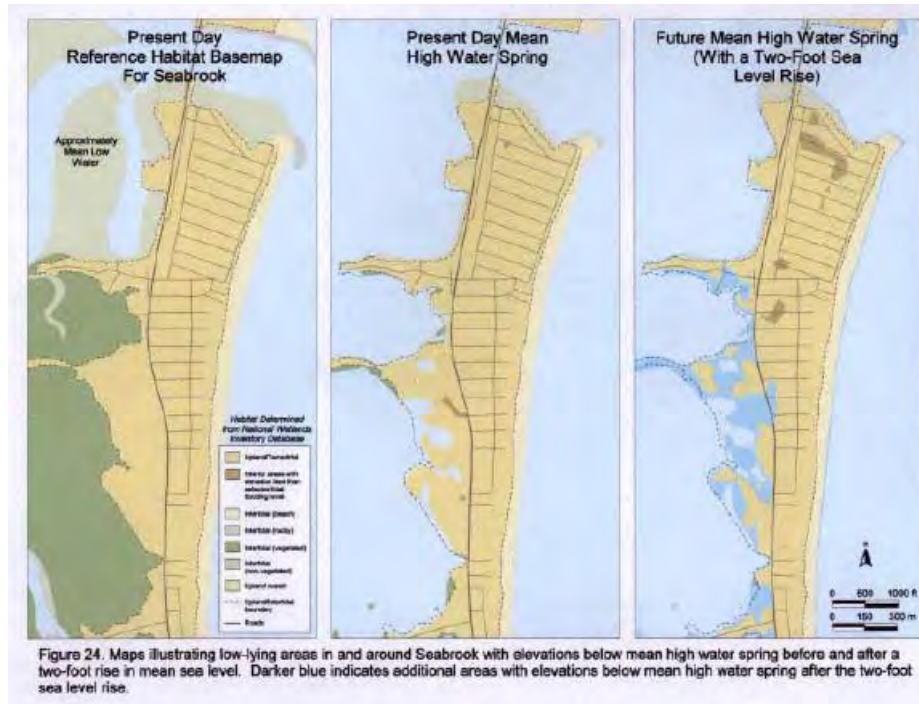


Figure 4. Increases in the areas flooded in Seabrook, NH with a two foot increase in tidal height due to sea level rise. From Ward and Adams (2001).

Salt marsh data sources and methods

Salt marsh extent

The historic marsh layer was developed from 1894 and 1934 topographic maps. Digital copies of the maps were obtained from the University of New Hampshire Library Digital Collections Initiative. The maps were georeferenced and the boundaries of saltwater marsh (indicated by shading in 1894 or a unique symbol in 1934) were digitized; the 1934 map was used in conjunction with the 1894 map due to the increased resolution in delineation of the upland extent of salt marshes. The 1894 and 1934 salt marsh distributions were merged to form the historic marsh layer.

Coastal wetland cover data for New Hampshire were developed for the NH Coastal Program by Normandeau Associates, Inc. from aerial photography from 2004. The salt marsh data were extracted from the wetland cover dataset and used for the current salt marsh distribution in NH (NHCP 2004). Salt marsh data for Massachusetts (MA Department of Environmental Protection 2007) were obtained from the MA Geographic Information System website (www.mass.gov/mgis/). Data from both sources (NHCP 2004 and MA DEP 2007) were merged to form a layer of the current distribution of salt marshes in the Hampton-Seabrook Estuary.

Salt marsh change analysis

The historic salt marsh data (USGS 1894 and USGS 1934) were overlain with and clipped by (as with a cookie cutter) the current marsh data (NHCP 2004 and MA DEP 2007); the area remaining was the total marsh loss. Areas of marsh loss were verified with the USDA SCS 1954 Rockingham County soil survey for NH and the 1925 USDA SCS Soil Survey of Essex County in Massachusetts. These maps were very useful in identifying areas of marsh fill and other losses. In the late 19th century, coastal topographic maps (“t-sheets”) were developed by the U.S. Office of Coast Survey. T-sheets for the Hampton-Seabrook watershed were found for 1855, 1866, and 1912 and downloaded from NOAA’s National Ocean Service Data Explorer (<http://oceanservice.noaa.gov/dataexplorer/whatsnew/welcome.html>). Due to the higher resolution depicted in these maps relative to the other data sources, the t-sheets were used to further verify and adjust marsh loss polygons, identify additional areas of marsh loss that predate the USGS maps, and delineate historic boundaries between salt marsh and sand dune habitats. The area of the watershed west of the B&M rail line was not included in the historic t-sheets; therefore, the marsh loss depicted west of the train tracks has not been verified with this higher resolution data source.

Salt marsh impacts

The NHCP 2004 wetland cover data mapped by Normandeau Associates, Inc. were coded by wetland type and include cover of invasive species. Data for the invasive variety of common reed (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), perennial pepperweed (*Lepidium latifolium*) and cattails (*Typha* species) were extracted to depict the occurrence of invasive wetland species in NH. Because no digital data were available for MA, the presence of invasive species (in marsh loss polygons only) in MA was determined with the high resolution oblique angle photography available through the “bird’s eye” feature of Windows Live Search maps. Presence of invasive species in MA is not represented as polygons, but is listed in the attribute table of the salt marsh loss shapefile.

Tidal restrictions were digitized from the document “Evaluation of Restorable Salt Marshes in New Hampshire” (NRCS 1994) and coded as restored, partially restored, restricted, or unknown. The tidal restriction upstream of the Taylor River dam as well as a tidal restriction in Salisbury were digitized and added to this layer.

Ditches were identified using the 2003 Emerge aerial photography in NH (obtained from NH GRANIT) and 2005 imagery for MA (obtained from MASS GIS) and were digitized based on the methods of Glode (2004).

Feasibility of restoration

Each area of marsh loss was evaluated for a suite of features to determine the feasibility of restoration at each site. Feasibility was determined subjectively and coded as high, medium, or low based on the following attributes:

1. Condition of the 150 and 200 foot buffers (NH only; buffer data obtained from the Complex Systems Research Center at UNH). Buffers play a critical role in coastal

- resiliency as they allow for the landward expansion of marsh habitats as sea level rises.
2. The conservation status of the land or adjacent lands (conservation data for NH obtained from GRANIT; data for MA obtained from MASS GIS)
 3. The current use and/or ownership of the property
 4. The presence of impacts including the density of ditches, tidal restrictions, and the presence of invasive vegetation.

In general, areas of marsh loss located near high quality buffers and/or adjacent to conservation land were considered more desirable for restoration. Areas rated as having a high feasibility of restoration were those where one or more impacts were present (i.e., ditching, invasive species, tidal restriction), the current land use is suitable for restoration, and the data sources used to delineate the lost marsh are of high resolution. Areas with a medium feasibility of restoration are typically those where impacts are not as severe and/or there is less confidence in the data sources used to delineate marsh loss. For these areas, groundtruthing is recommended prior to site selection and restoration planning to verify that the area was formerly marsh. (This is indicated in the 'Feasibility notes' column of the attribute table for the shapefile "Marsh_loss.") Low feasibility areas are typically those where the current use precludes restoration (e.g., roads, houses, commercial development).

Error estimation

Inherent in all maps is some degree of error and uncertainty. Historic maps are subject to greater potential error due to the fact they were typically created at larger scales than present day resulting in less accurate delineations. Furthermore, the process of georeferencing a historic map, or aligning an image to spatial data and relating it to a projection, adds an additional source of error. Due to the potential for spatial variability in georeferencing unprojected images and using different data sources, error was estimated for the 1894 and 1934 data sources that were used to determine historic salt marsh extent. Maps were first georeferenced into a NAD83 NH State plane projection and aligned with current topographic maps. Road intersections and other features that do not change over time were set as control points. The root mean square (RMS) error is calculated by the georeferencing tool in ArcMap as the distance from a georeferenced control point to a control point specified by the user. It serves as an estimate of the error resulting from the georeferencing process. The RMS error for the 1894 and 1934 topographic maps were estimated at 28.7 and 6.9 m, respectively. A second analysis of error (S. Gaughan, NH DES, personal communication, 27 Aug 2008) was conducted to determine the average offset between feature sizes in historic data sources and current high resolution aerial photography. Ten locations were selected on each historic map, measured and compared to the same feature on the aerial photograph. The size differential for each feature was calculated and averaged to determine the mean offset error. The offset error associated with the 1894 and 1934 topographic maps was calculated as 26.5 and 29.2 m, respectively. Therefore, the boundaries of salt marsh habitats delineated from historic topographic maps are accurate within 26.5 m (1894 map; 1:62,500 scale) and 29.2 m (1934 map; 1:62,500 scale). These values are

considered acceptable due to the fact that they fall within the error standard set by U.S. National Map Accuracy Standards (accuracy of 32.2 m for 1:62,500 scale).

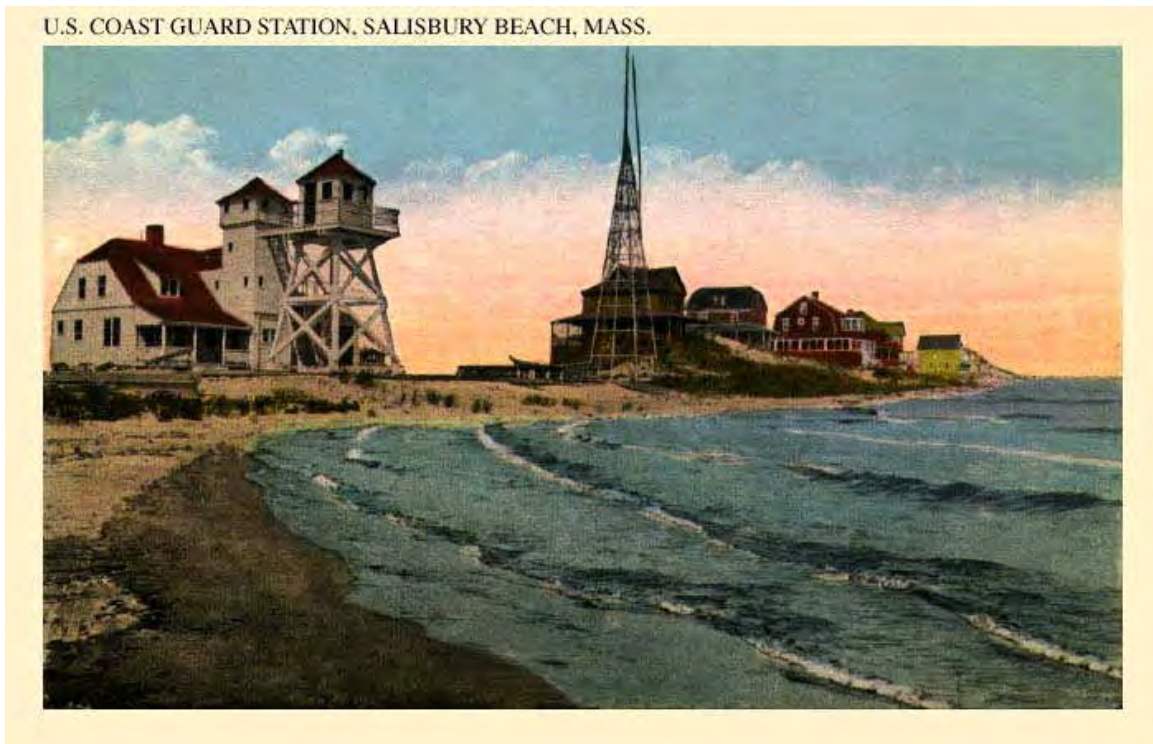
An additional source of potential error is the content accuracy of a map. Potential error exists in the delineation of natural features from maps and aerial photographs. Furthermore, errors may occur within a dataset from misidentification of species, soil, and habitat types or the mislabeling of information. As a primary step in confirming a restoration site and gathering data to support a preliminary restoration design, on the ground data collection is needed to confirm or modify information determined through image analysis. In this way, all the potential mapping and classification errors can be addressed and prevented from interfering with restoration.

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Sand Dunes



Postcard credit: http://www.salisburybytheseashore.com/html/historical_photos_23.html

Sand dune overview

Sand dunes form in high energy environments where the wind moves fine grained sand from wave swept beaches landward to form dunes. Dunes are dynamic and interesting ecosystems that provide important ecological functions including: shoreline stabilization, storm buffering, and habitat for common species such as white-tailed deer, and an array of uncommon animals specialized for survival in dunes (including rodents, insects and nesting birds). Sand dunes can be delineated into three general zones: foredune, interdune, and backdune. Foredunes are located closest to the ocean and are the most dynamic due to the high level of exposure to waves and wind. They are primarily colonized by American beachgrass (*Ammophila breviligulata*). The dense root systems of dune vegetation play a vital role in anchoring shorelines. Interdunes are located landward of foredunes; they are characterized by higher species richness than foredune and are less dynamic. Landward of the interdune is the backdune. Backdunes are the most stable and mature part of a dune system; they are characterized by large, woody vegetation such as shrubs and trees. Even so, few species can survive and the upper and seaward branches of the hardest trees and shrubs are often pruned where winds carrying salt spray are the most severe.

Despite their recognized natural values, the position of dunes as the highest elevation land in between ocean and marsh resources rendered the land extremely

valuable and thus, vulnerable to development. Early maps suggest that some of the first areas colonized in the Estuary were the high points of dunes. Development of sand dunes has continued over time due to the desirability of beach access for businesses and homes. As a result, the majority of historic dunes in the Hampton-Seabrook Estuary (83.6%) have been destroyed. The Seabrook Dunes (west of route 1) is the largest area of intact sand dune and the only remnant backdune in the state. Where remnant foredune and interdune does exist in front of homes along Seabrook and Salisbury beaches, they have been damaged by devegetation and excessive cut-throughs created by beach goers in lieu of using municipal beach access.

The sustainability of a dune system requires that all parts of the dune receive regular sand inputs. Due to varying weather patterns, the natural tendency of sand dunes is to migrate as winds, waves and storm activity accrete and remove sand. However, the high level of development along the dunes of the Hampton-Seabrook Estuary has impeded the natural replenishment of sand as well as precluded the ability of the shoreline to shift. Modification of this natural process does not prevent the restoration of dunes; rather, it creates the need for sand dune restoration activities to be continually managed over time to mimic the natural processes of sedimentation and erosion.

Sand dune restoration methods

Dune creation

Where dunes have been destroyed or become unstable due to high levels of impacts, they are often rebuilt by importing sand to increase the dune height and/or width. Sand can be obtained from a remote source or when possible, from a local dredging project, and mechanically moved to the dune creation site. Sand can also be accreted in situ by establishing semi-permeable barriers such as sand fencing or vegetation to decrease wind velocity and promote the deposition of sand. Such techniques that take advantage of natural dune-building processes are typically used in foredune systems.

Dune creation projects can be costly when earth-moving equipment is used to replenish sand, although in some cases these projects can be conducted together with dredging activities where the dune creation is a beneficial use of the dredge spoil. By combining dredging and dune building, transportation and disposal costs can be reduced. A much lower cost is associated with dune creation projects where sand fencing is used; however, this approach may require more maintenance, particularly in reconstructing fencing after large storms.

Planting

Vegetation is frequently planted to stabilize foredunes in instances where a dune has become unvegetated or in concert with dune creation projects. American beachgrass is the most commonly planted species; it is an aggressive pioneer species that can withstand the harsh conditions (e.g., wind, salt exposure, low nutrients) of the foredune.

As it lays its dense network of roots and rhizomes, beachgrass is effective at preventing erosion of dunes. Although beachgrass is the most commonly planted dune species in the northeast, research by the USDA NRCS has demonstrated that many other species characteristic of dunes can be successfully planted. Planting alternative species is an effective approach when the goal of restoration is to increase species diversity or when interdune or backdune areas are the target of the restoration effort.

A relatively low cost is associated with planting projects. To ensure greater success, plantings may need to be fertilized and irrigated during initial establishment. Planting projects can be labor intensive; however, the use of community volunteers is an effective way to increase the planting effort while providing opportunities for outreach. Planting projects have previously occurred in the watershed, including an effort in 1993 to plant 40,000 beachgrass culms along the foredune in Seabrook as well as a more recent effort in the foredune of Salisbury Beach.

Education

Most of the remaining dunes in the Hampton-Seabrook Estuary occur on privately owned land. Therefore, gaining community understanding and support for dune restoration and preservation efforts is fundamental to dune persistence. Informational mailers, interpretative signs near dunes, and community meetings can all be effective ways of conveying information to the community. In areas where private residences abut sand dunes, or where public beaches necessitate access through dunes, paths should be limited and clearly marked to avoid unnecessary impacts to dunes. In the Hampton-Seabrook Estuary, private pathways created from beach front properties through dunes to access the beach are quite common. Research conducted in the Plum Island, MA dune system found that trampling, such as from walking paths, reduced the species diversity of the dune vegetation. Specifically, the prevalence of the rare interdune plant community decreased as beachgrass exploited the disturbed habitat. In order to maintain the interdune community as well as the overall diversity of dune vegetation, paths should be limited to municipal access ways. Homeowners and beachgoers should be engaged to garner their understanding and support for efforts to limit and prevent foot paths through dunes. Sand fencing placed at each end of the paths can serve to limit further foot traffic as well as capture sand to aid in rebuilding the dune. Where private beach access is allowed, design standards should be mandated for pathways that minimize impacts to dune function, such as through elevated walkways. Such standards have been developed for the town of Salisbury, Massachusetts (Salisbury Beach Dune Walkover Access Design Standards; available from the Salisbury Conservation Commission at www.salisburyma.gov/PB-CC/CCbeachaccessdesignstandards.pdf).

Conservation

Particularly in light of the scarcity of dunes in the Hampton-Seabrook Estuary, efforts to conserve existing dunes are essential if the state is to maintain even the remnants of these extremely rare habitats. Important dune areas can be conserved through activities such as statutory and regulatory protection, land use management, and

acquisition of lands. Collaboration of communities, citizens, government agencies and conservation organizations is important to developing and implementing conservation strategies. Funding sources from state, federal and private programs currently exist to support dune conservation efforts.

Sand dune data sources and methods

Analysis of sand dune change over time

A high resolution digital copy of a map created by J.F.W. Des Barres in 1776 was obtained from the National Maritime Museum in Greenwich, UK. Des Barres was a military engineer hired by the British government to conduct a survey of the Atlantic coast of North America. As a result, Des Barres' charts contain an incredible amount of detail, including the distribution of sand dunes. The 1776 Des Barres map was georeferenced and the distribution of sand dunes digitized to create the 1776 data layer. Data for 1894 and 1934 sand dunes were developed from digital USGS historic topographic maps obtained from the University of New Hampshire Library Digital Collections Initiative. After these maps were georeferenced, the sand dunes were digitized based on the color change and topographic contours delineating the sand dune habitat. Data for current sand dune distributions were delineated and digitized from the 2003 Emerge aerial photography (obtained from NH GRANIT) and 2005 aerial photography for MA (obtained from MASS GIS). These data were ground-truthed and corrected by field survey for all but the southernmost extent of the Estuary.

Sand dune change analysis

Historically, the shoreline of the Hampton-Seabrook Estuary was quite dynamic and shifted dramatically over short time periods (see Figure 2), and in turn, the distribution of sand dunes moved as well. Due to the difficulty in identifying loss of sand dune habitat in such a dynamic estuary, the historic sand dune distribution was chosen from a point in time after the inlet was hardened (i.e., when the jetties were installed in 1930). Therefore, the historic sand dune data for the change analysis were derived from the 1954 USDA Soil Conservation Service Soil Survey of Rockingham County, NH and 1925 USDA Soil Conservation Service Soil Survey of Essex County, MA. Soil maps were scanned and georeferenced, and sand dune distributions digitized. It should be noted that the soil maps do not necessarily represent the surface soil condition or the particular use of a given parcel of a land at the time of the survey, but rather the underlying soils. As a result, the 1925 and 1954 soil mapping represent a distribution of sand dune habitat we believe to be the best estimate of pre-development conditions prior to the high level of development that had occurred in the area by 1925/1954.

The historic dune layer was clipped with the current dune layer to determine the areas of dune lost. The layer of dune loss was further delineated into areas impacted by fill and development, areas lost to salt marsh encroachment, and areas with high potential for restoration. Areas of current dune were delineated into dune community types based on the community classification system of the NH Natural Heritage Bureau (D. Sperduto,

personal communication, 9 June 2008). Data for community types were collected by field survey and from Dunlop and Crow (1985).

Error estimation

The RMS error and mean offset error were calculated for the historic data sources for sand dunes (see the salt marsh methods section for a complete discussion of potential error sources and error calculations). The RMS error for the 1776, 1894 and 1934 maps were estimated at 33.5, 28.7 and 6.9 m, respectively. The offset error associated with the 1776, 1894 and 1934 topographic maps was calculated as 26.4, 26.5 and 29.2 m, respectively. Therefore, the boundaries of sand dune habitat delineated from the 1776 Des Barres map are accurate within 26.4 m. This value is only slightly greater than the U.S. National Map Accuracy Standard (accuracy of 25 m for 1:50,000 scale). The boundaries delineated for the historic USGS topographic maps are accurate within 26.5 m (1894 map; 1:62,500 scale) and 29.2 m (1934 map; 1:62,500 scale). These values are considered acceptable due to the fact that they fall within the error standard set by U.S. National Map Accuracy Standards (accuracy of 32.2 m for 1:62,500 scale).

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Diadromous fishes



Photo credit: Sue Foote

Diadromous fishes overview

Adapted from Odell et al. 2006

Diadromous fishes are those that migrate between fresh and salt water as a requirement to complete their life cycle. The species are further classified as either anadromous, those fishes that live predominantly in saltwater and move to freshwater to reproduce (e.g., alewife, blueback herring, American shad, rainbow smelt, Atlantic salmon, Atlantic sturgeon, and sea lamprey) or catadromous, species that spend the majority of life in freshwater and migrate seaward to spawn (e.g., American eel). Within both riverine and coastal environments these species have specific habitat requirements for feeding, spawning and refuge. These requirements and the stress associated with the physiological changes needed to transition between fresh and salt water render these species extremely vulnerable to habitat impacts within freshwater and marine migratory corridors. In particular, juvenile salmonids, shad, and river herring are very sensitive to low dissolved oxygen levels, with altered behavior and severe stress at levels around 5 ppm and mortality possible as levels approach 3 ppm. Low oxygen levels in water impounded behind dams that have fish ladders may be a strong physiological barrier limiting diadromous fish populations.

The Taylor River is one of the largest tributaries to the Hampton-Seabrook Estuary. The system has experienced severe declines in fish populations, particularly river herring, in the past few decades despite a fish ladder. Low water levels and low oxygen concentrations may limit diadromous populations in the Taylor River. Low oxygen conditions can occur due to excessive nutrients and are exacerbated by low flow conditions that occur in part because of freshwater withdrawals for human needs. In addition to the negative impacts of high water temperature and subsequent lowered oxygen levels, the quantity of water flowing in the Taylor River can be a problem. Intense spring floods can impede the movement of adults upstream and reduced summer flows can leave juvenile fish trapped in small stressful impoundments, unable to migrate downstream.

Little data on historic distributions of diadromous fishes exist for the Hampton-Seabrook Estuary. However, it is clear from European settlers' accounts of the fish resources found in the Estuary, as well as discussions with long time residents of the area that thriving fish populations once existed. A report after the 1723 storm that created Meadow Pond discusses how eels were so abundant that they could easily be captured in great numbers without any bait. Other accounts reference the abundant river herring and eels captured in the Hampton River. In 1881, Reverend Roland Sawyer recounts how on trips out to cut marsh hay with his father he enjoyed catching the tomcod and horseshoe crabs that were commonly found in the salt pannes.

In recent decades migratory fish populations have suffered precipitous declines. NH Fish and Game has conducted annual river herring (i.e., alewife and blueback herring) surveys at the Taylor River Dam fish ladder since 1976 when they counted 450,000 river herring moving through the ladder. The numbers have continued to decline over time with a record low in 2006, when only 147 river herring were recorded returning upstream to spawn. The Blackwater River and the Hampton Falls River are also major tributaries where diadromous fish may have flourished. Interviews with local fishermen further confirm the overwhelming decline of fish in the Estuary, particularly with respect to eels, smelt, river herring and shad.

In addition to the construction of mill dams on New Hampshire waterways as early as the 17th century, other sources cite the abundant sawdust input from mills, sewage, agricultural runoff, and fishing pressure as causes of the decline of diadromous species. Many dams still exist today, blocking fish movement between upstream and downstream areas. Restoration efforts for diadromous fishes began in the 1960s and 1970s with the construction of fish ladders to facilitate fish movement across dams. Currently, the only fish ladder present in the Hampton-Seabrook Estuary is the Taylor River Dam fish ladder. This fish ladder is reported to pass several diadromous species, including American eels, lamprey, alewives and blueback herring, but with varying degrees of success over time. Although fish ladders can improve access to upstream areas for some species, overall conditions are far from optimal. Salmon and sturgeon populations are virtually extinct in the region due to degraded habitat, fragmentation and changes to hydrology. Dams are not the only barriers to fish passage. Many culverts used for road-stream crossings serve as barriers because of inadequate size, shape, design,

installation, and maintenance. Historical stressors combined with rapid development and associated water and habitat quality issues threaten all diadromous species in the Hampton-Seabrook Estuary. Both new and continuing efforts are being made to restore diadromous fishes to the region. A draft feasibility study has recently been completed by the Louis Berger Group, Inc. for removal or replacement of the Taylor River Dam to better accommodate fish passage.

Diadromous fishes restoration methods

Adapted from Odell et al. 2006

Dam Removal

Dam removal involves the removal or breach of an instream structure that diverts or impounds water. Dam removal can benefit all fish species that use riverine habitats. In addition to restoring fish passage to upstream areas, dam removal can increase fish habitat quality by restoring water flows, and in turn, sediment and nutrient flow. It may also restore a brackish salinity region that is important to the life histories of many fishes, including rainbow smelt. Furthermore, dam removal is a permanent restoration that does not typically require ongoing maintenance or attention.

Dam removal requires the consideration of complex social and ecological factors, including the cost and time required for evaluation and permitting as well as land and water uses that may be affected by changes in streamflow and sedimentation patterns. Concerns vary from project to project, however in most cases, the issues associated with dam removal can be mitigated.

Nature-Like Fishways

Nature-like fishways (NLF) have been constructed in Europe, Canada, Australia, and Japan and have recently become more accepted as a dam removal alternative in the United States. Each NLF is carefully designed to mimic the natural conditions in the river reach that has been blocked. Unlike fish ladders, successfully designed and constructed NLF can pass most or all naturally occurring species and also provide good quality stream habitat for the plants and invertebrates that help to support migratory fish. However, because the dam and impoundment are left intact, NLFs do not restore the hydrology of the system and negative impacts associated with impoundments (e.g., water quality, sedimentation, streamflow, etc.) remain.

Fish Ladder

A fish ladder is a series of ascending pools or steps with flowing water that allows some fish species to pass over barriers such as dams. Installation of fish ladders is often a more practicable restoration option when barrier removal is not feasible. Fish ladder installation is typically more economically feasible than barrier removal but does not significantly correct altered hydrologic regimes. While this may be considered a limitation in terms of fish restoration, in some circumstances fish ladders may be the only

practical way to provide passage over dams that are not practical to remove.

Because fish swimming ability varies by species and life history, design flow requirements for fish ladders are species specific. Therefore, one fish ladder cannot pass all species. Fish ladders have proven successful at passing species such as river herring, and to lesser degrees for American shad; however, fish ladders have not yet been designed to attract all diadromous species. Fish ladders act as filters, allowing passage for certain species during specific flow conditions. Creating appropriate flow strength and orientation to attract target species can be difficult, and real-world performance often falls short of engineering design goals. While fish ladders are less expensive than dam removal, they still require a substantial monetary investment, often correlated with the height of the barrier. Furthermore, fish ladders typically require maintenance such as debris removal and flow control.

Culvert Enhancement or Replacement

Scientists and resource managers are increasingly looking at culverts as a source of stream habitat fragmentation. New Hampshire recently concluded the first comprehensive, watershed-scale assessment of the impacts of culverts on stream habitat continuity in the Ashuelot River watershed (located in southwestern New Hampshire), so there is now well-developed methodology for field assessment and analysis that could be readily applied to Hampton-Seabrook Estuary tributaries (Bechtel and Ingraham 2008). Additionally, new tools and guidelines have been developed to promote fish and stream-friendly culvert design. The Massachusetts Stream Crossing Handbook is one good example.

Stocking

Fish stocking involves the release of adult and juvenile fishes into a river targeted for restoration. Fish may be captured and transported from rivers supporting healthy, sustainable runs, or may be trapped in the lower reaches of a river and moved above an impoundment. Fish may also be hatchery produced and introduced into the target river in the juvenile stage. Stocking programs can serve to accelerate the recovery rate of target species, particularly when transported within a basin where fishes are more likely to be adapted to local conditions. Furthermore, stocking may restore ecological functions supported by diadromous fishes such as secondary production.

When stocking hatchery reared fish, hybridization of hatchery reared with native fishes may serve to dilute the native gene pool. Furthermore, the movement of fishes from one system to another may introduce diseases and parasites into the recipient system. When it is the sole restoration approach, large-scale stocking efforts must continue to maintain a large population, because stocking alone does not address the causes of fish population decline.

Habitat Restoration

Diadromous fish restoration can occur through efforts to improve water and substrate quality. Examples of habitat restoration projects include shoreland buffer restoration to address runoff and erosion issues, storm water runoff treatment to improve water quality, and restoration of stream channel morphology to increase floodplain habitat. Removing sources of habitat degradation promotes the long-term re-establishment of fish populations. Furthermore, habitat restoration addresses the overall ecological health of a system and therefore will benefit many species in addition to the target species. Particularly in more developed watersheds, the factors contributing to habitat degradation are often numerous and complex. These causes are often associated with non-point sources and, therefore, efforts to identify and address them can be costly and time consuming. Habitat restoration projects require scientific guidance, as well as continued monitoring and management following completion of the project to assure objectives are met.

Diadromous fishes data sources and methods

The New Hampshire Hydrography Dataset (NHHD) was obtained from the Complex Systems Research Center at the University of New Hampshire. Dams data for New Hampshire were obtained from the NH Department of Environmental Services Dams Bureau. Data for one dam in Massachusetts was obtained from Massachusetts Riverways. The only other dam located in the Massachusetts extent of the watershed was identified by field survey and its location was digitized.

Using the ‘locate features along routes’ tool in ArcToolbox, the dams not positioned along the flowline feature of the NHHD were aligned to the closest point on the stream network. The ‘make route event layer’ tool was used to display the newly defined locations of the dams data along the NHHD stream network as an event layer. The data were then exported to the shapefile, “NH_MA_dams.shp”.

Data for species occurrences were collected from historic anecdotal accounts, fish surveys, and interviews with local fisherman. Data were transferred to a large map that was then reviewed by fish experts at NH Fish and Game. The NHHD data were exported as a shapefile to enable editing, and the attribute table was populated with current and historic species occurrences for stream sections upstream and downstream of each dam. Fish distribution codes are based on those used by Odell et al. (2006):

- H probable or known that fish were historically present and are currently absent, based on historical records or expert review
- C probable or known that fish are currently present, based on historical records or expert review
- HU possible that fish were historically present (based on expert opinion), but no specific record exists

- CU possible that fish are currently present (based on expert opinion), but no specific record exists
- 0 probable or known that fish are not currently present and were not historically present, based on historical records or expert review

Note: The “U” suffix is used to denote uncertainty.

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Results

Salt marsh change analysis

Currently, the Hampton-Seabrook Estuary contains 1802.5 hectares (ha; 4454 acres) of salt marsh (Figure 5). The current extent of salt marsh has been reduced by 248.4 ha (613.7 acres) relative to the historic extent (2050.9 ha; 5067.7 acres) due to various habitat impacts. Table 1 lists the extent of the impacts. It should be noted that the areal extent of impacts is not additive due to the fact that multiple impacts may exist in a given area.

Table 1. Extent of salt marsh impacts

Impact	Area/Length
Tidal restrictions	185.2 ha (457.7 acres)
Invasive vegetation*	34.8 ha (85.9 acres)
Direct loss (e.g., fill)**	183.3 ha (453.1 acres)
Ditches	606.9 km (377.1 miles)

* The values for invasive vegetation indicate the amount of current or historic salt marsh currently colonized by one or more of the following invasive species: *Phragmites australis*, *Lythrum salicaria*, *Typha* spp. The total amount of these species in the tidal portion of the watershed is 42.5 ha (105.1 acres).

** Direct loss includes marshlands that have been directly filled for development as well as upland edges that the change analysis detected as marsh loss.

Areas of marsh loss were coded according to the feasibility of restoring salt marsh at each site (Figure 6; determination of feasibility is outlined in the salt marsh Methods section). The total areas of marsh loss according to feasibility of restoration include tidal restrictions, invasive control and fill removal, but not ditch remediation. These areas are presented in Table 2.

Table 2. Area of marsh loss by restoration feasibility

Feasibility of restoration	Area
Low	108.5 ha (268.1 acres)
Medium	64.4 ha (159.2 acres)
High	74.5 ha (186.5 acres)

Figure 5. Historic and Current Salt Marsh Extent

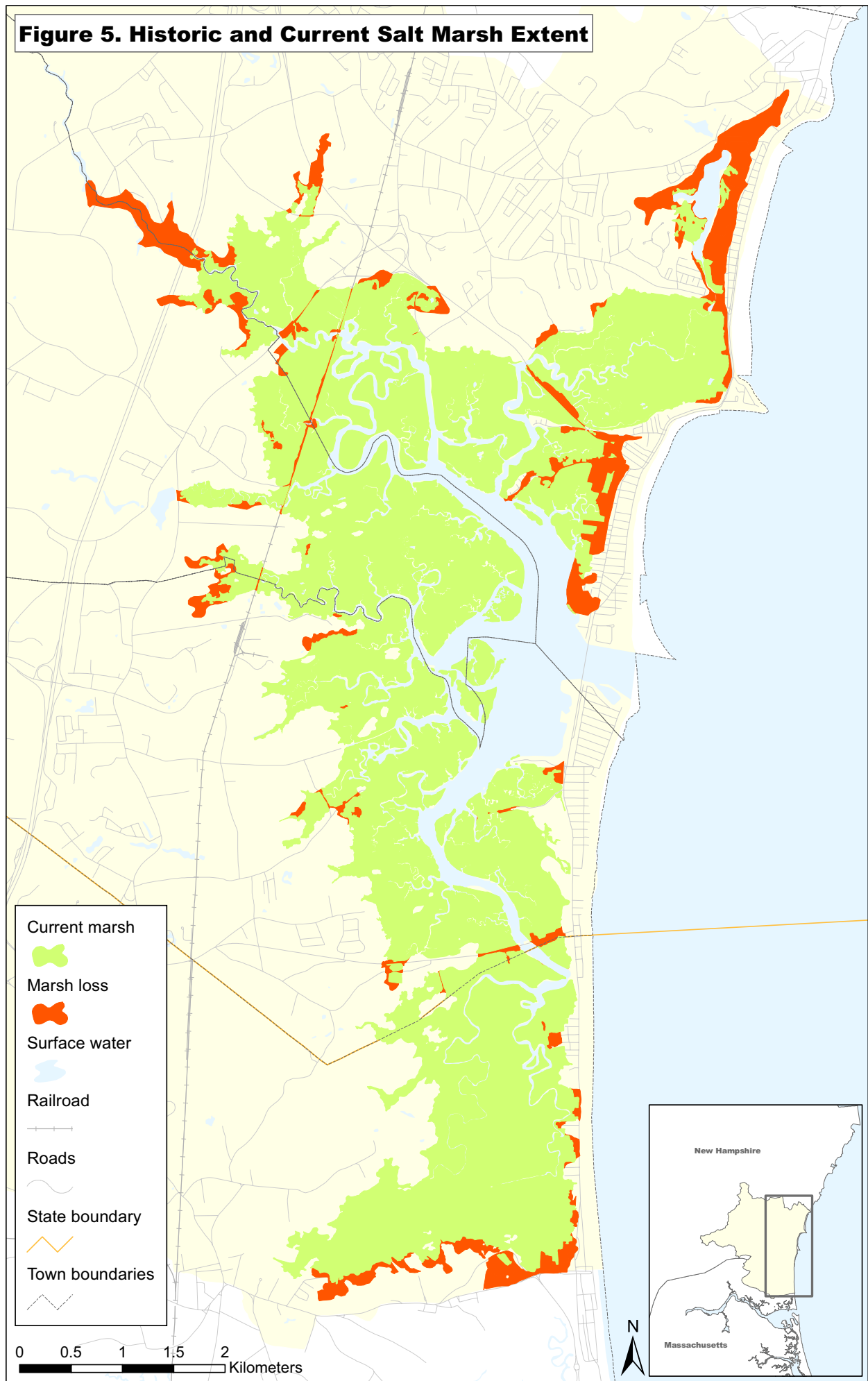
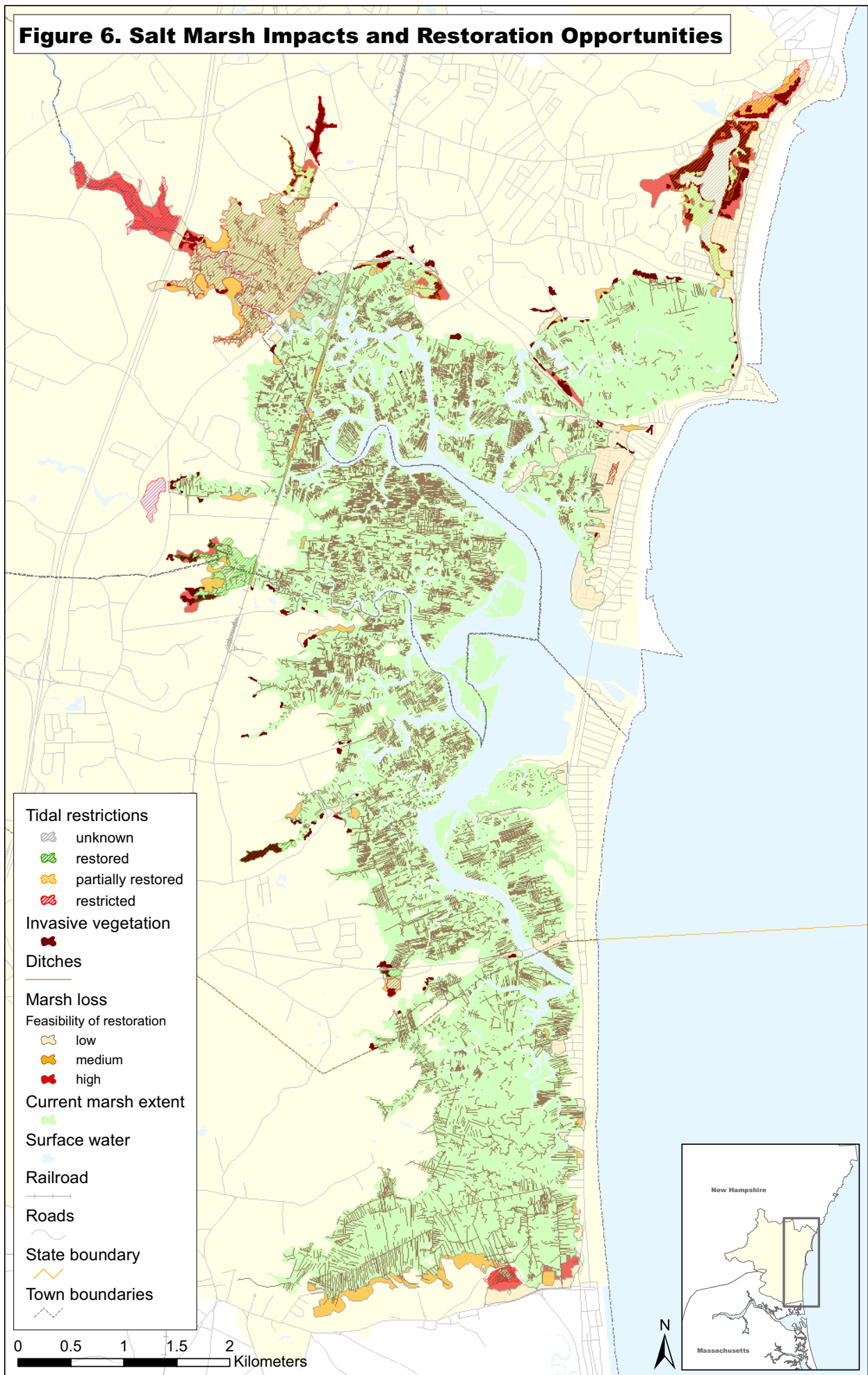


Figure 6. Salt Marsh Impacts and Restoration Opportunities



Sand dune change analysis

The extent of sand dune habitat in the watershed was evaluated from 1776 to the present (Figures 7 and 8). Over the past 230 years, 83.6% of the total area of sand dune habitat in the watershed has been lost. Table 3 includes the area of sand dune calculated for each survey year as well as losses.

Table 3. Dune extent over time.

Year	Area	Percent of historic (1776)
1776	293.0 ha (724.0 acres)	100 %
1894	170.4 ha (421.0 acres)	58.2 %
1934	94.4 ha (233.2 acres)	32.2 %
2005	48.0 ha (118.7 acres)	16.4 %

The appreciable amount of dunes lost is attributed largely to development and current uses that make restoration difficult (Figure 9). Table 4 lists the area of dune lost to development and encroachment of salt marsh habitat (both considered to have low feasibility of restoration). Table 4 also includes dune areas with various impacts that appear to be easily reversible (e.g., devegetated existing dunes, walkways through dunes, recreational areas). Such areas have a high potential for restoration.

Table 4. Dune habitat impacts and area of high restoration potential*

Impact/restoration potential	Area
Fill and development/low	247.9 ha (612.5 acres)
Salt marsh encroachment/low	8.1 ha (20.1 acres)
Disturbance/high	30.0 ha (74.1 acres)

* Dune loss was calculated from a historic dune extent delineated from the 1954 USDA Soil Conservation Service Soil Survey of Rockingham County, NH.

The 48.0 ha (118.7 acres) of sand dune habitat currently present in the Hampton-Seabrook Estuary were delineated into community types from a field survey as well as the data presented in Dunlop and Crow (1985; Figure 10). Community types were defined according to the NH Natural Heritage Bureau (D. Sperduto, personal communication, 9 June 2008). Table 5 includes the total area of each dune community type currently present within the watershed.

Table 5. Current dune extent by community type

Community type	Area	Percent of total
Beach grass grassland	34.2 ha (84.6 acres)	71.2 %
<i>Hudsonia</i> maritime shrubland	6.3 ha (15.6 acres)	13.1 %
Bayberry beach plum maritime shrubland	4.3 ha (10.6 acres)	8.9 %
Maritime wooded dune	2.8 ha (6.8 acres)	5.8 %

Figure 7. Sand Dune Extent Over Time

The geomorphology of the inlet has changed over time. The dune extent for each year is mapped over the current shoreline, hydrography and roads data.

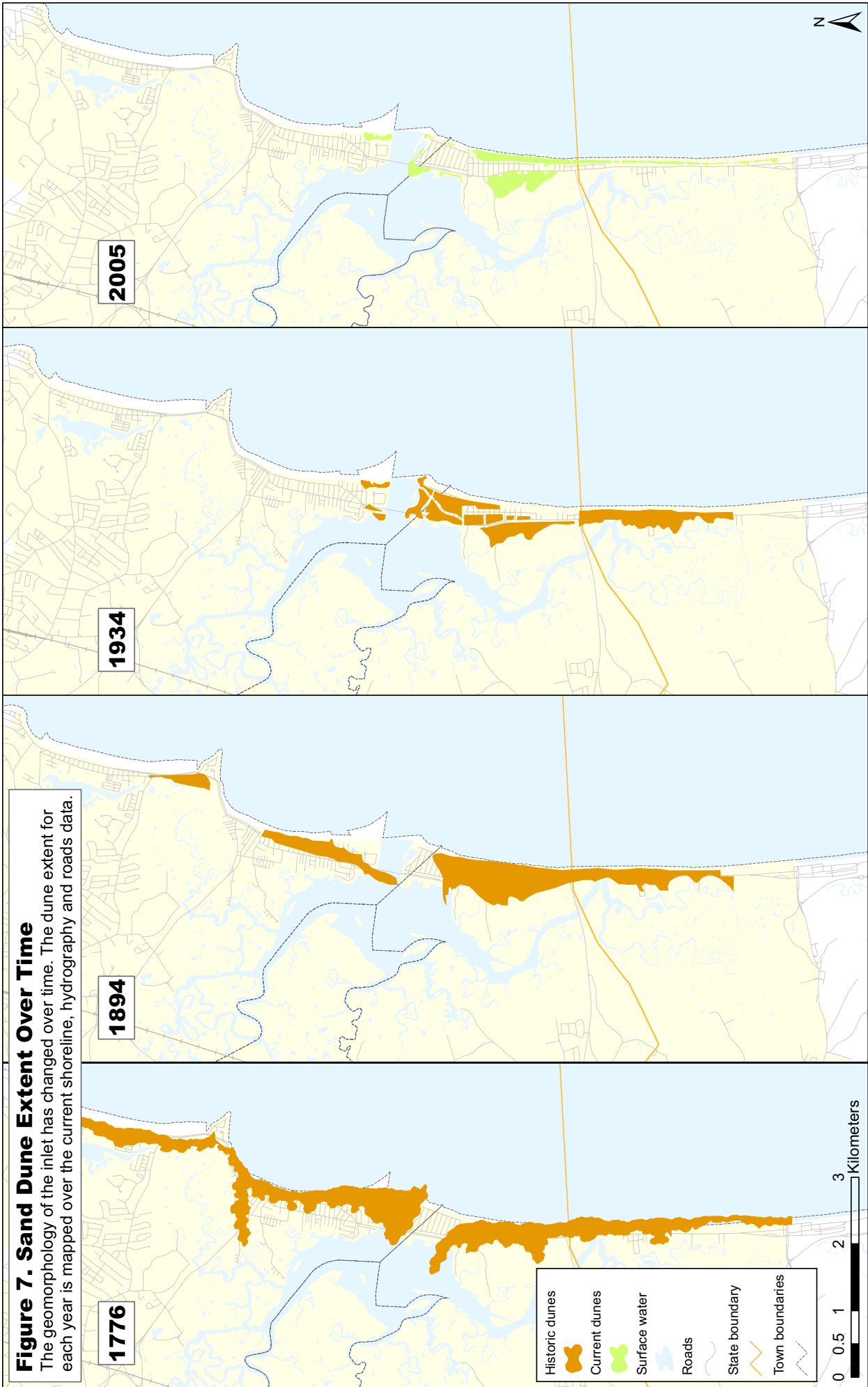


Figure 8. Historic and Current Sand Dune Extent

Historic dunes are based on the USDA 1954 soil survey

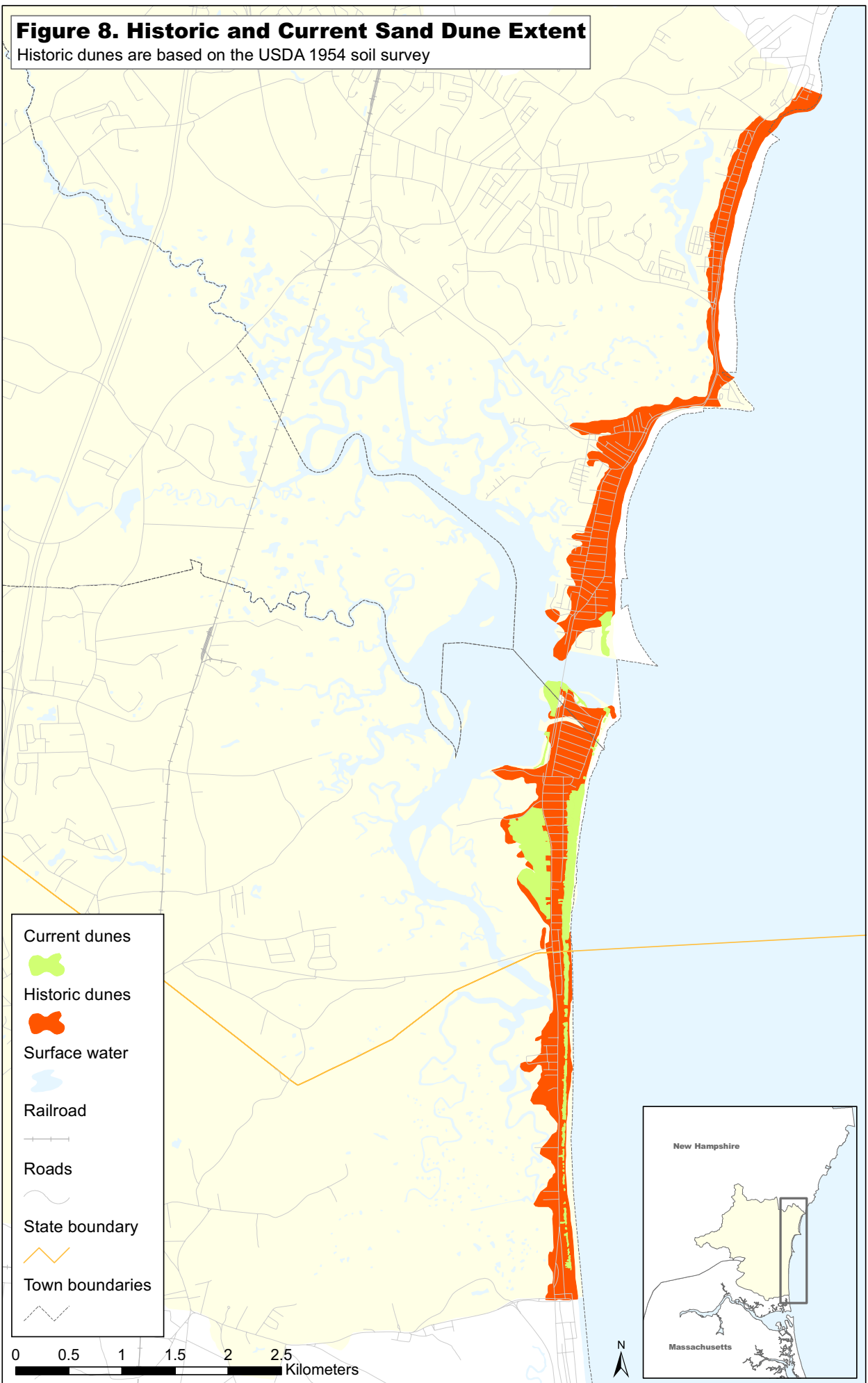


Figure 9. Sand Dune Restoration Opportunities

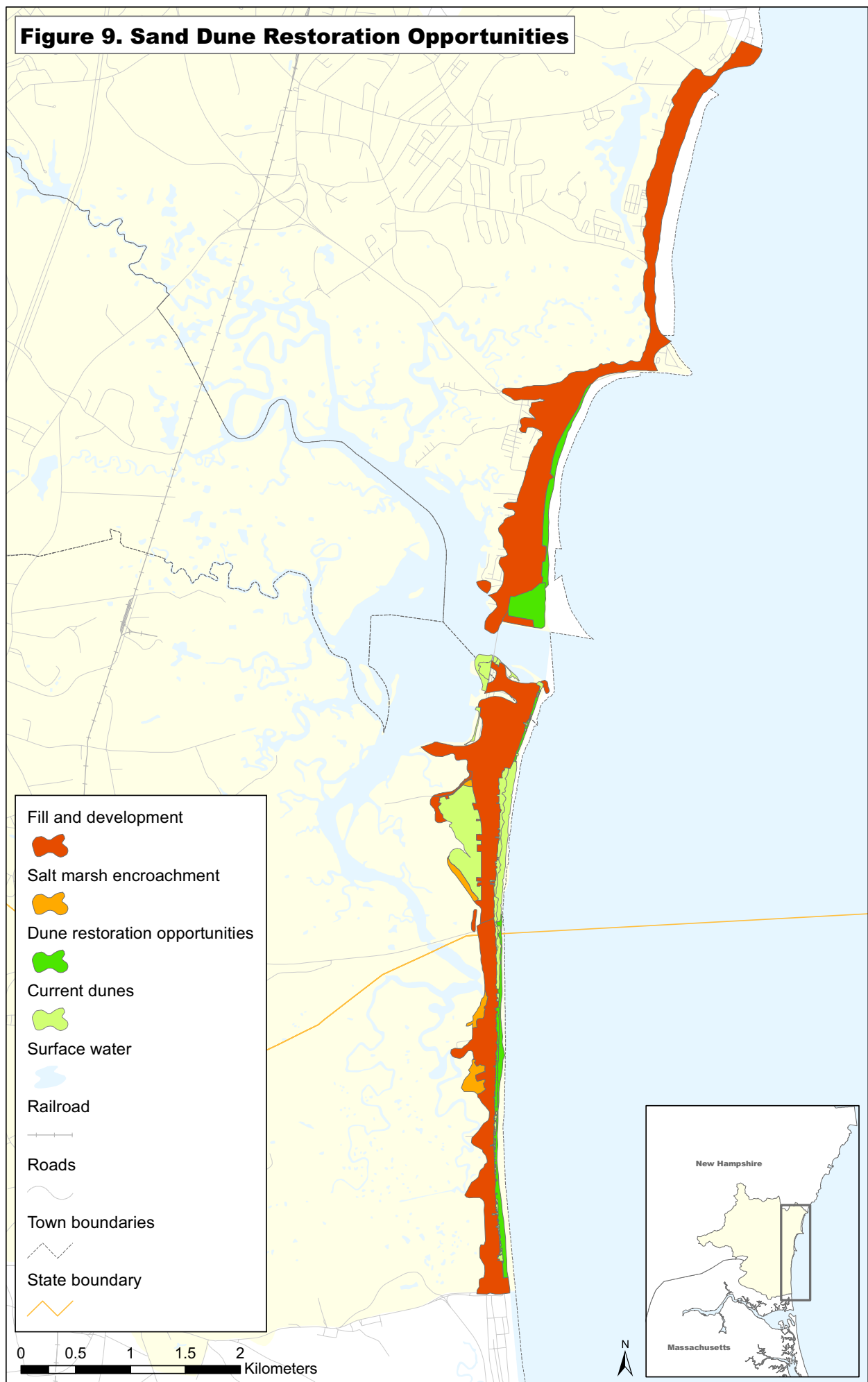
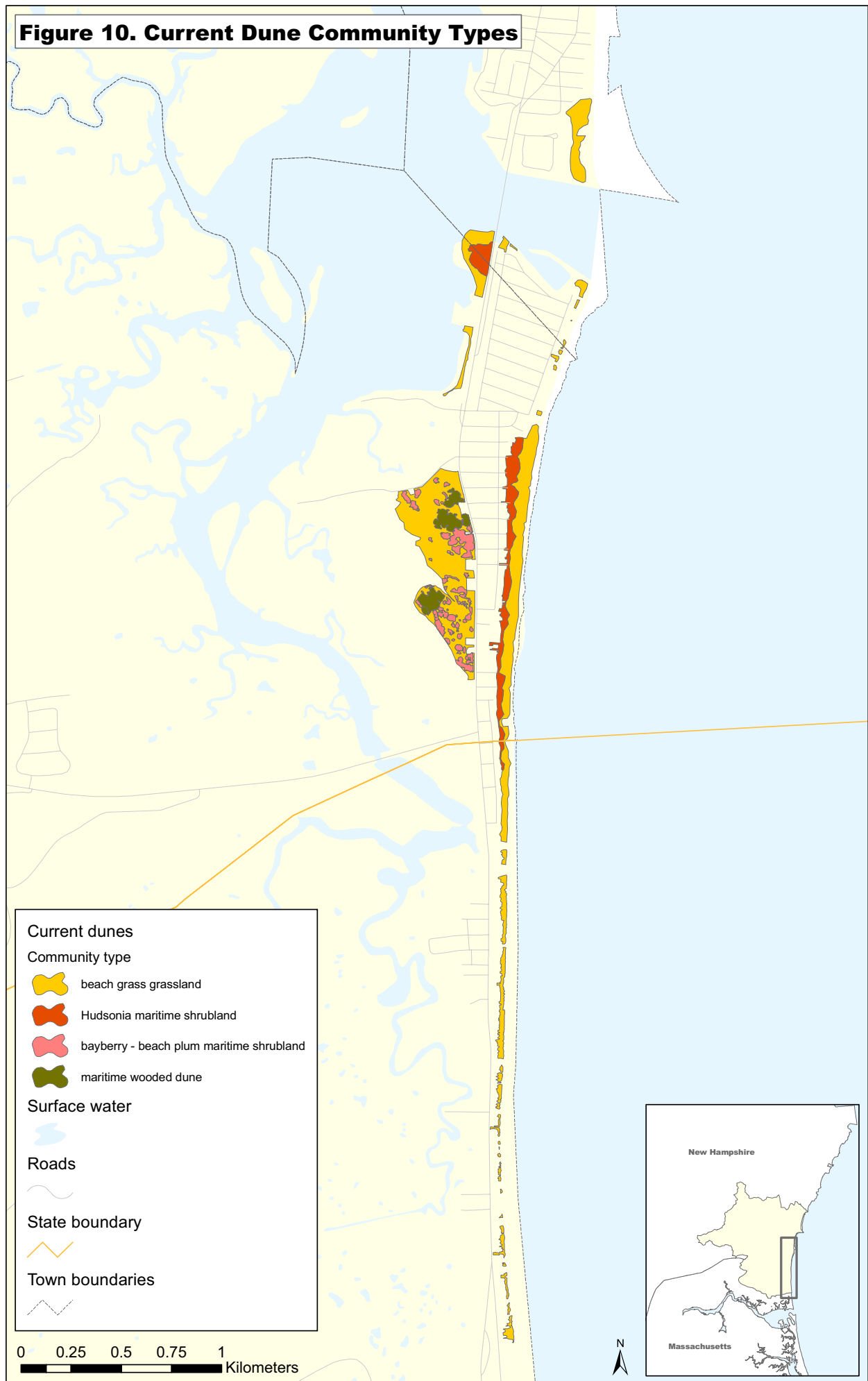


Figure 10. Current Dune Community Types



Diadromous fish stream network analysis

The following tables contain data for the amount of river miles in each river system available to diadromous fish. Each table follows the same format. The first column (Mainstem dams) identifies by ordinal number each dam along the main corridor of each river. The second column (Mainstem river miles upstream from the estuary) lists the length, in river miles, from the open estuary (defined as the inlet to the harbor) to each successive dam (i.e., lengths are cumulative). The final row in the second column (upstream terminus) is the total length of the mainstem river. The third column (Currently unobstructed miles, including tributaries) lists the number of mainstem and tributary river miles upstream of each dam until the next obstruction. The fourth column (Cumulative connectivity potential) lists the length of the river system, in river miles, that would be gained by installing fish passage at or removing each successive dam. The first row of the fourth column lists the number of river miles that are currently unobstructed in that system. The last column (System percent) lists the amount of the river system, as a percent of the total river system, that would be gained by installing fish passage or removing each successive dam. It should be noted that the downstream-most dams are the most important to target for removal in order to restore connectivity and increase available fish habitat. The last two rows indicate the length of tributary streams currently obstructed by dams and the length of the river system historically connected (i.e., the total length of the river system), respectively. With each table is a brief narrative describing current and historic use of each system by the seven target diadromous fish species for this project: alewife, blueback herring (these two species are collectively known as river herring), American shad, rainbow smelt, Atlantic sturgeon, Atlantic salmon and the American eel. Data for each species' current and historic distribution in the watershed are presented in figures 11-16.

Tide Mill Creek – Meadow Pond

The Tide Mill Creek-Meadow Pond system is located in the northeast section of the watershed in the town of Hampton, NH. Tide Mill Creek is a meandering creek comprised of relatively unditched salt marsh habitat. Currently, Tide Mill Creek likely serves as a foraging and refuge habitat for eels, river herring, shad and smelt. Historically, river herring, shad and smelt likely spawned in this system. A section of the system is named Eel Creek, suggesting that eels were once very abundant in the system. Like the rest of the watershed, while eels are currently present, their populations are greatly reduced relative to historic numbers. In fact, eels are in decline over their entire range (NOAA NMFS 2008); likely causes include migration barriers due to dams, hydroturbine mortality, overfishing, and habitat loss (Haro et al. 2000).

A culvert under Winnacunnet Road that restricted tidal flow to upstream regions was replaced in 1995 with a larger culvert. While the hydrologic restoration and subsequent excavation work were effective at increasing tidal influence in Meadow Pond, large area of vegetated marsh remain dominated by *Phragmites*. The freshwater headwaters upstream of Meadow Pond may provide suitable habitat, particularly for river herring, but are currently disconnected from downstream reaches by two dams.

Table 6. Tide Mill Creek - Meadow Pond stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			23.3	
First	5.6	1.4	24.7	96.1%
Second	6.6	1.0	25.7	100.0%
Upstream terminus	7.6			
		Blocked tributary miles	0	0.0%
		Historically connected	25.7	100.0%

Drakes River

The Drakes River system runs through Hampton, NH and is located in the northern section of the watershed. Adult river herring have recently been observed in this system. Although alewives are not spawning in the Drake’s River due to the lack of access to freshwater habitat, there is a possibility that blueback herring could spawn due to their ability to spawn in low salinity water (although these are suboptimal conditions). Shad have recently been captured downstream of this system, so they may be using it for foraging. River herring, rainbow smelt, and shad can likely be found in this system up to the first obstruction at river mile 7.7. Historically, these species were likely abundant in this system as they used it for spawning, foraging and rearing habitat. Eels are currently in this system, but in reduced numbers relative to historic populations. The Drakes River system is too small to have supported sturgeon or salmon populations.

Table 7. Drakes River stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			11.3	
First	7.7	0.4	11.7	80.7%
Second	8.1	0.9	12.6	86.9%
Third	8.6	0.4	13.0	89.7%
Fourth	9	1.1	14.1	97.2%
Upstream terminus	9.1			
		Blocked tributary miles	0.4	2.8%
		Historically connected	14.5	100.0%

Taylor River

The Taylor River flows through the towns of Kensington, Stratham, Exeter, Hampton and Hampton Falls, NH. The Taylor River Dam is located just south of the route 95 and 101 interchange. A fish ladder exists on the first dam that passes river herring; however, numbers have decreased steadily over the past 3 decades and the condition of the dam has deteriorated. Furthermore, the dam created a large impoundment upstream that suffers from poor water quality that may be limiting spawning success and fish use of the area. In fact, dissolved oxygen values (% saturation) violated water quality standards in 74% of samples collected from the impoundment in June – October 2008 (Berger 2009). If fish passage and water quality issues can be remediated, high quality habitat exists upstream to potentially support spawning populations of river herring and shad. A draft feasibility study has currently been completed to evaluate options for restoring fish passage at the Taylor River dam, either through dam removal or installation of a fish passage structure (Berger 2009).

Historically, shad, river herring, smelt, and eels were common in this system. Currently, remnant populations of all of these species are present, but in greatly reduced numbers. Reports of increases in the numbers of shad in the system have been reported over the last 10 years. However, no evidence exists for any current spawning population of this species. The Taylor River system is likely too small to have supported populations of sturgeon or salmon.

Table 8. Taylor River stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			19.4	
First (fish ladder)	7.3	6.0	25.4	47.8%
Second	8.6	24.5	49.9	94.0%
Upstream terminus	12.3			
		Blocked tributary miles	3.2	6.0%
		Historically connected	53.1	100.0%

Hampton Falls River

The Hampton Falls River courses through the towns of Kensington, Hampton Falls, and Seabrook, NH. Historically, this system likely supported spawning populations of smelt, shad, and river herring. Eels were also very common in this system. At present this river supports foraging by low numbers of these species, with no known spawning populations. Although this river has the highest density of dams of any of the rivers in the watershed, it has the greatest potential for spawning habitat due to the low level of development in surrounding areas. Atlantic salmon and Atlantic sturgeon historically were not likely found in this system because it is too small to have supported the preferred habitats of these species.

Table 9. Hampton Falls River stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			5.7	
First	4.4	0.3	6.0	31.9%
Second	4.7	0.1	6.1	32.4%
Third	4.8	0.3	6.4	34.0%
Fourth	5.1	3.3	9.7	51.6%
Fifth	7.1	4.4	14.1	75.0%
Sixth	9	0.1	14.2	75.5%
Seventh	9.1	0.3	14.5	77.1%
Eighth	9.4	3.7	18.2	96.8%
Upstream terminus	12.1			
		Blocked tributary miles	0.6	3.2%
		Historically connected	18.8	100.0%

Cains Brook-Mill Creek

Cains Brook originates in Salisbury, MA and courses largely through Seabrook, NH to the point where it becomes tidal and is known as Mill Creek. Historically, smelt, river herring, and eels were all likely common in this system. Shad may have historically been present. Eels, alewives and smelt can currently be found in the system; however barriers prevent access to potential spawning habitat. High sediment load as well as water quality issues (such as organochlorides) currently prevent suitable spawning habitat.

Table 10. Mill Creek - Cains Brook stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			8.3	
First	4.1	1.3	9.6	70.1%
Second	4.7	2.7	12.3	89.8%
Upstream terminus	6.3			
		Blocked tributary miles	1.4	10.2%
		Historically connected	13.7	100.0%

Blackwater and Little River

The headwaters of both the Blackwater and Little Rivers are located in Salisbury, MA. The confluence of these two rivers is located just south of the state boundary between MA and NH. They join to form the larger Blackwater River that flows through Seabrook before emptying into Hampton Harbor. These rivers may be the only ones in the watershed to have supported Atlantic sturgeon, who prefer larger river systems. Historically, this system supported river herring, shad and smelt. While no evidence for spawning populations exists for any of these species, they are all likely using these rivers as a foraging resource. As with all the systems in the watershed, the Blackwater and Little Rivers currently support eels, but in greatly reduced numbers relative to historic populations.

Table 11. Blackwater River stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
None	7.6		57.8	
			57.8	99.8%
		Blocked tributary miles	0.1	0.2%
		Historically connected	57.9	100.0%

Table 12. Little River stream network analysis

Mainstem dams	Mainstem river miles upstream from estuary	Currently unobstructed miles, including tributaries	Cumulative connectivity potential	System percent
			32.5	
First	5.7	5.6	38.1	100.0%
Upstream terminus	7.9			
		Blocked tributary miles	0	0.0%
		Historically connected	38.1	100.0%
Note: Beaver dam may exist further upstream on Smallpox Brook				

Figure 11. Historic and Current Distribution of Alewives and Blueback Herring

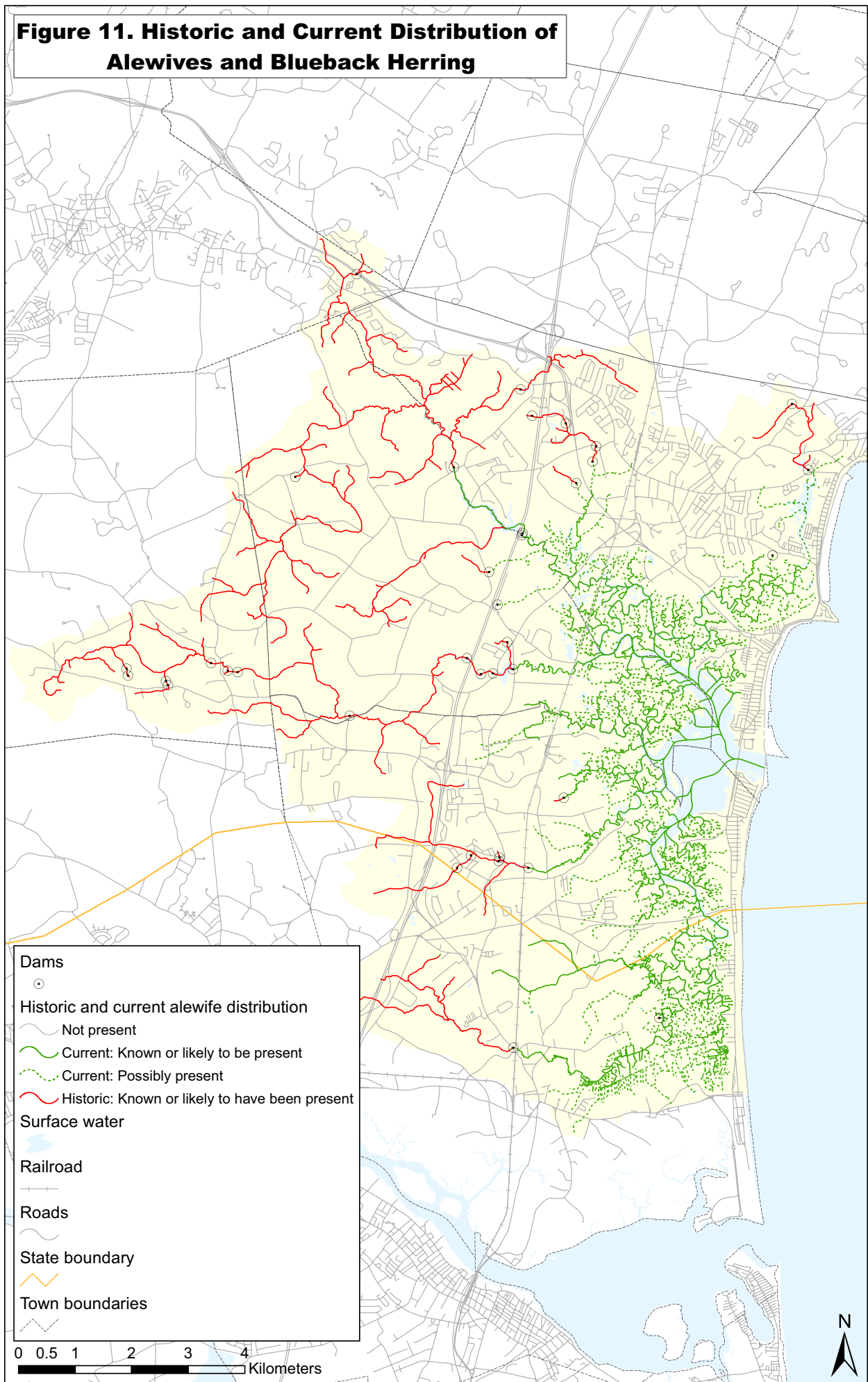


Figure 12. Historic and Current Distribution of American Shad

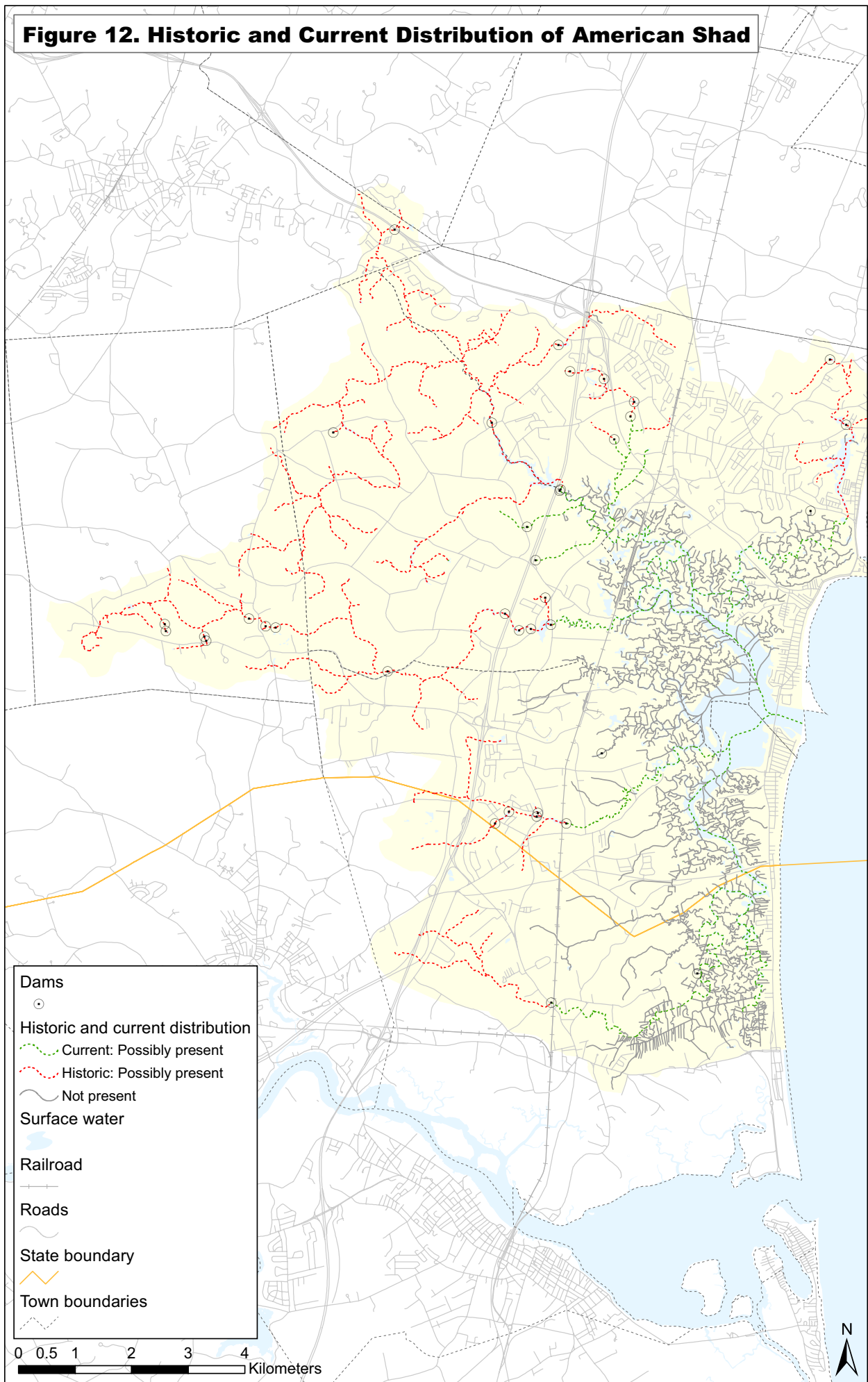


Figure 13. Historic and Current Distribution of Rainbow Smelt

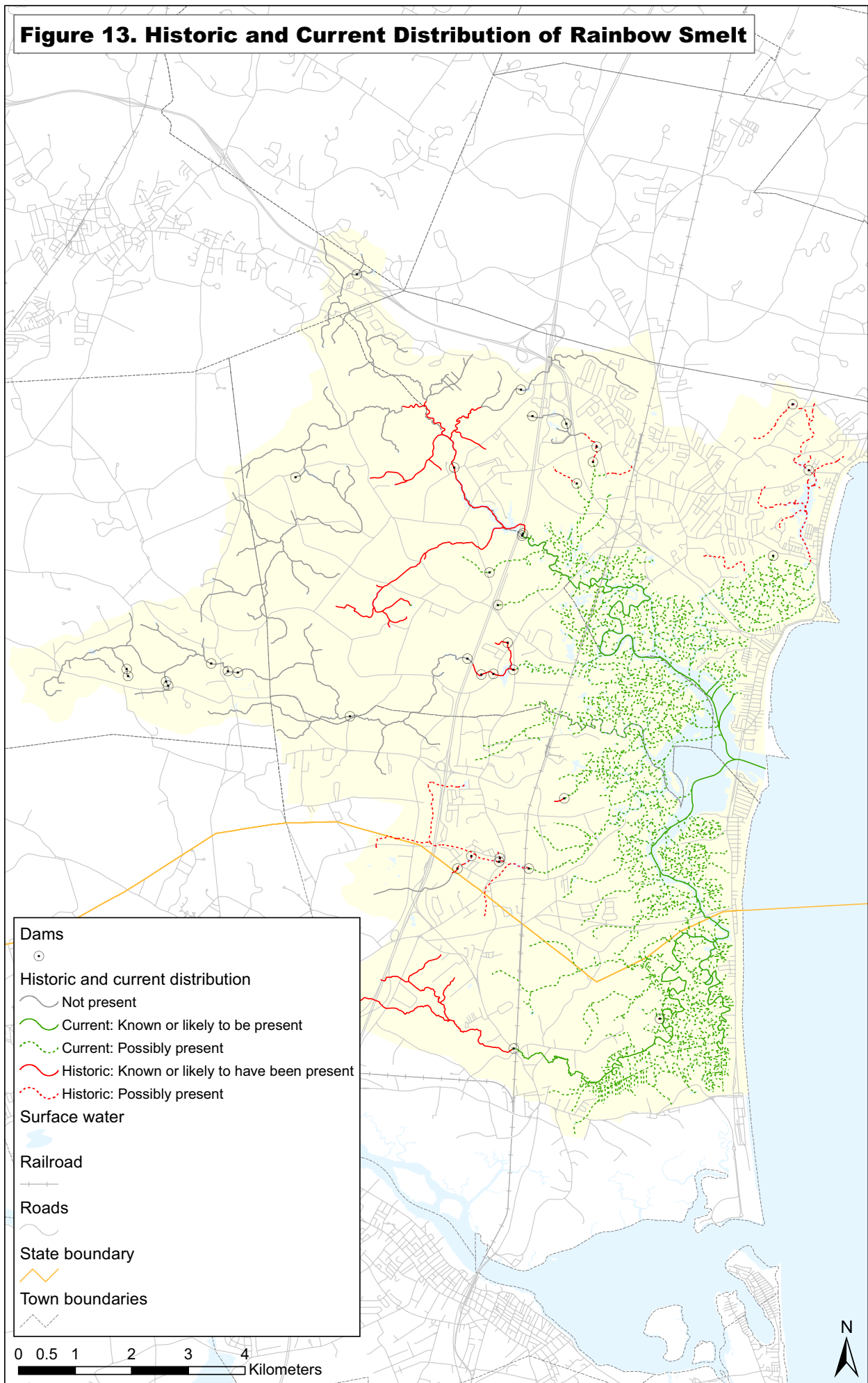


Figure 14. Historic and Current Distribution of American Eel

Although eels are currently found throughout the Hampton-Seabrook Estuary, populations are likely greatly reduced relative to historic numbers.

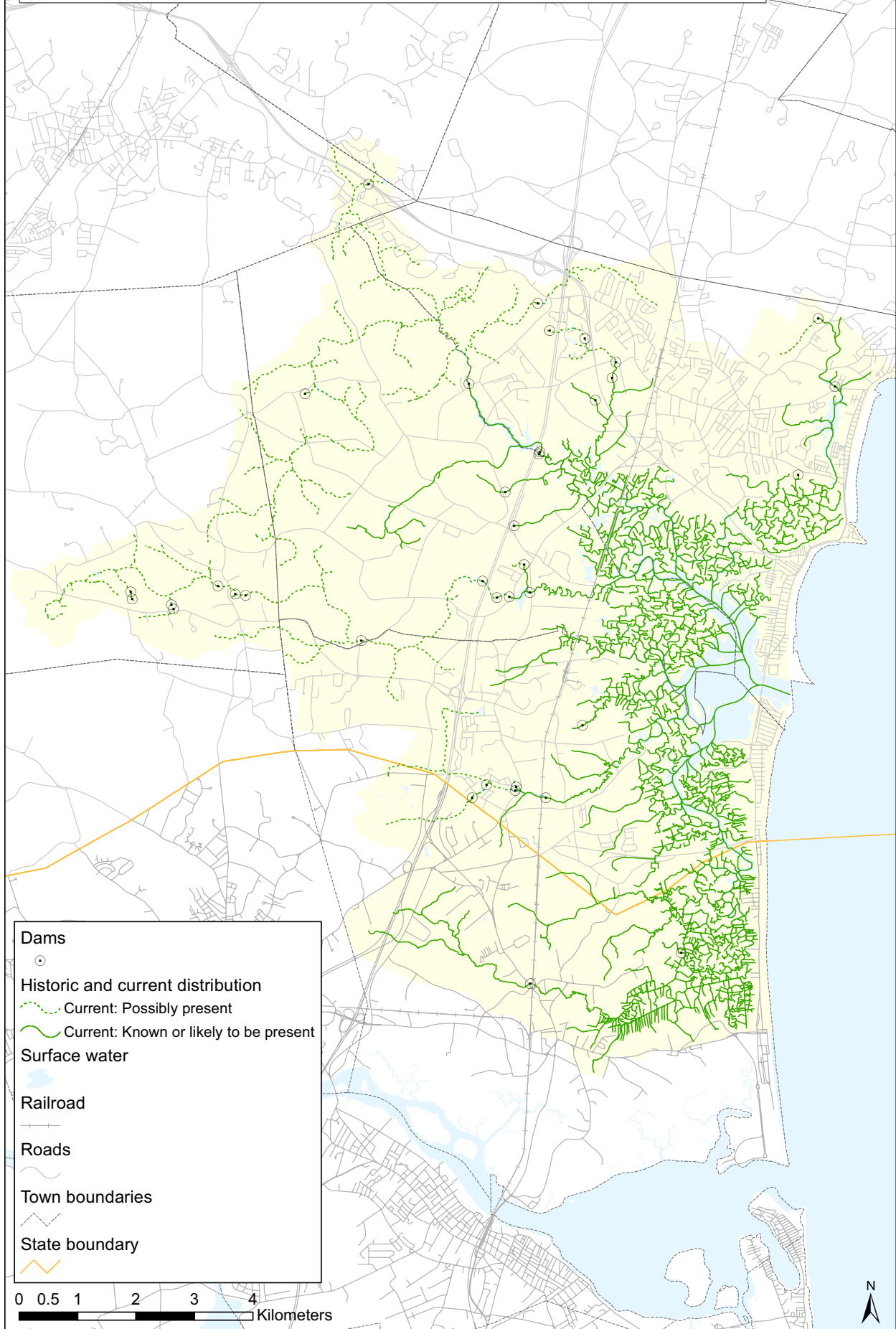


Figure 15. Historic and Current Distribution of Atlantic Salmon

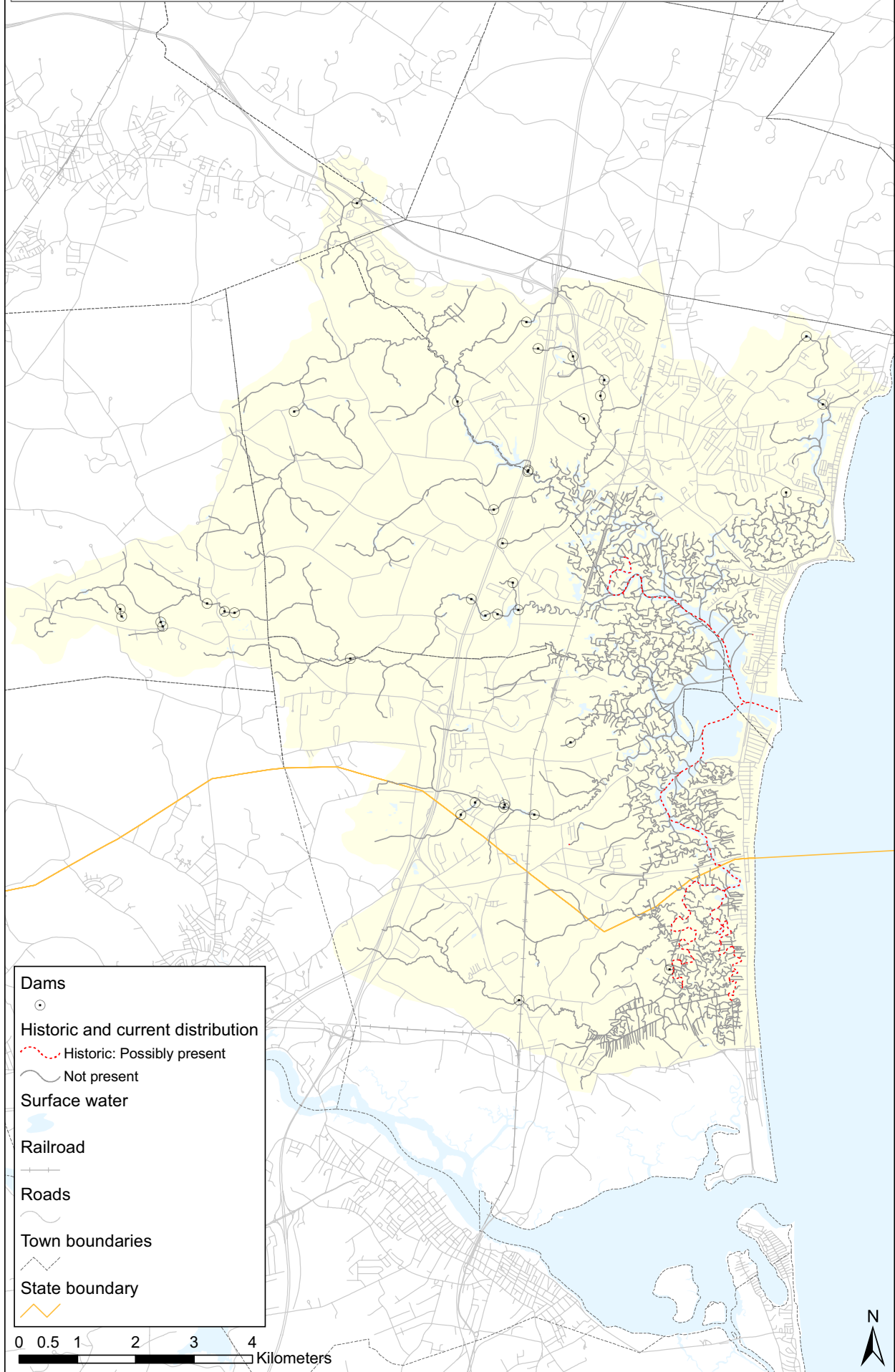
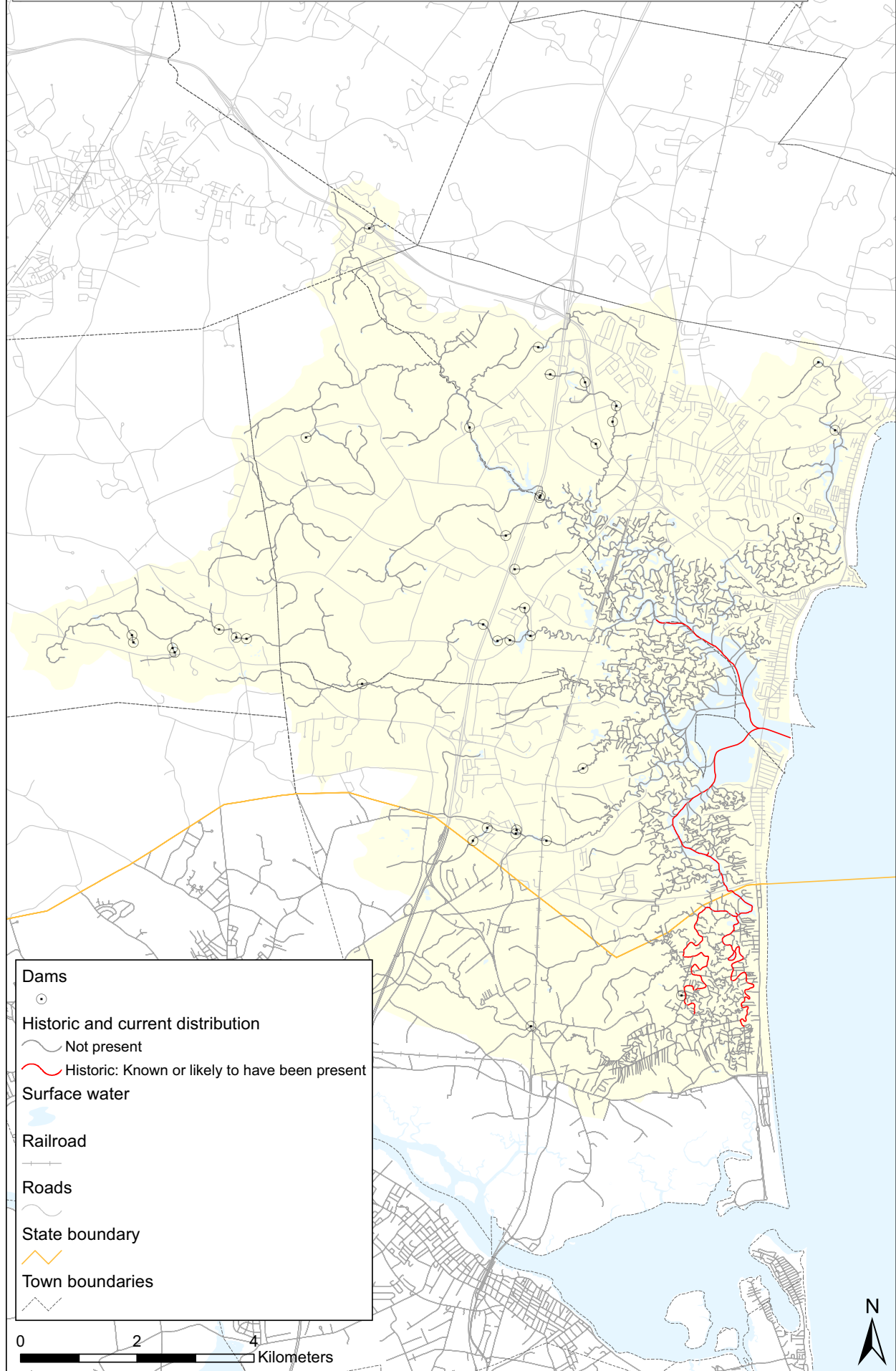


Figure 16. Historic and Current Distribution of Atlantic Sturgeon



Prominent restoration opportunities by subwatershed

Below is a list of example restoration opportunities. This list is by no means exhaustive; rather, it lists some of the more prominent opportunities within the watershed. Opportunities are listed by subwatershed. The number next to each restoration opportunity is used to indicate the location of each area on the corresponding restoration opportunity map.

Tide Mill Creek – Meadow Pond subwatershed (Figure 18)

1. Meadow Pond – Tidal flow to the upstream area was partially restored with the installation of a larger culvert in 1996. However, due to the high level of development adjacent to the area, tidal flow could not be fully restored. As a result of the reduced tidal flow and high inputs of stormwater runoff, *Phragmites* is abundant at this site. Methods for eliminating *Phragmites* and increasing tidal flow should be explored. This area was identified as an important shorebird foraging site at high tidal stages by NH Audubon (McKinley and Hunt 2008).
2. Marsh upstream of route 101– Unlike the majority of the Estuary, the salt marsh habitat in this region is characterized by very little ditching. Due to the high habitat and research value of this area of marsh, it is recommended that conservation efforts be focused here. Further, the NH Audubon Society identified this area as a conservation priority due to the high density of saltmarsh sharp-tailed sparrows as well as evidence of breeding willets (McKinley and Hunt 2008).
3. Tide Mill Creek – A large area of fill exists upstream of route 101 in Hampton that is currently colonized by predominantly *Phragmites*. This site is considered a prominent restoration opportunity due to the threat of *Phragmites* spreading to the expanse of adjacent salt marsh. Furthermore, restoration efforts at this site would be highly visible and therefore, provide an excellent educational opportunity. This site is listed as a priority restoration opportunity by the Rockingham County Conservation Commission (RCCD 2005).
4. Hampton Beach State Park – Dunes located at this site have eroded and are subject to trampling due to the high use of this area. Revegetation of the areas impacted by humans is recommended. Furthermore, due to the high use of this area in the summer, it is recommended that dunes be protected from further impacts with fencing and signs. A large dune system formerly occupied this site prior to it being developed. Opportunities to remove fill from the area and restore a larger dune system should be explored, particularly because it is state owned land. The high visibility of this area warrants a large outreach campaign to inform park patrons of the value of dunes, the threats facing them, and what they can do to avoid impacting dunes.

Taylor River – Drake’s River subwatershed (Figure 19)

5. Railroad berm throughout Hampton and Hampton Falls - The berm that supported the now defunct rail operations through the western part of the salt marsh has resulted in alteration of creek channels (e.g., areas of scour in the Taylor River and the creek immediately to the south) as well as disruption of sheet flow across the

vegetated marsh. Exploration of options to regrade the elevation of this area down to tidal inundation is recommended.

6. Taylor River upstream of route 1 – An undersized culvert under route 1 restricts tidal flow to this region of the marsh. Restoration of this area of marsh was listed as a secondary priority by the Rockingham County Conservation Commission (RCCD 2005) due to the potentially high cost of restoring this site. Although some conservation land does exist in this region, further efforts to protect this area, as well as the surrounding upland buffer, should be pursued due to the relative lack of ditches. This region was noted as a conservation priority for bird habitat due to the concentration of saltmarsh sharptailed sparrows in the region, the presence of conservation land, as well as the relatively undeveloped upland buffer (McKinley and Hunt 2008).
7. Drakeside Road – A tidal restriction under Drakeside road was replaced in 1996 after the previous culvert was washed out in a storm. The current 4' x 8' box culvert is likely not providing adequate tidal flow to upstream areas, as evidenced by the prevalence of *Phragmites* upstream as well as observations of restricted tidal flow by the Rockingham County Conservation District. This site is listed in a RCCD (2005) document as a restoration priority. They recommend removal of rip rap to increase tidal flow, and possible installation of a second culvert to the west of the current one. An additional option is to replace the existing culvert with a larger one. This site was also identified as an important area for salt marsh sharp-tailed sparrows (McKinley and Hunt 2008); the impacts of improved tidal flushing on bird use should be considered prior to beginning restoration activities.
8. Towle Farm Dam – A small earthen dam on the Drakes River blocks fish access to upstream waters that could provide potential river herring habitat.
9. Downstream of the Taylor River Dam - Removal of *Phragmites* immediately downstream of the Taylor River Dam is recommended to enhance fish habitat. This area is subject to increased runoff from the NH State Liquor store on the northbound side of route 1. If left untreated, *Phragmites* may raise the marsh elevation and as a result, exclude anadromous and resident fish from the marsh adjacent to the river.
10. Taylor River Dam – Although the first dam on the Taylor River has a fish ladder to provide fish passage, it has deteriorated and in recent years it is not passing many fish. Furthermore, water quality issues in the impoundment upstream of the dam limit opportunities for fish use and access to upstream habitat. The upstream areas of this river system provide excellent fish habitat opportunities; in fact, the upstream region of the Taylor River is listed as a conservation focus area by The Nature Conservancy. A feasibility study is currently underway to evaluate restoration alternatives for the dam at this site.

Hampton Falls River – Brown's River – Cains Brook subwatershed (Figure 20)

11. Southern bank of Hampton River – The marsh along the southern bank of the Hampton River contains an extremely high density of mosquito ditches. A recent evaluation of avian use of the Estuary provides evidence for increased salt marsh sharp-tailed sparrow and shorebird use of unditched sites for foraging and roosting (McKinley and Hunt 2008). A doctoral student at the University of New Hampshire

is currently evaluating the impacts of ditches and ditch management methods on marsh functions. Despite these efforts, very little is known about the impacts of ditches on salt marsh function. Research is recommended to investigate experimental methods for ditch management.

12. Sea level rise protection - To allow for natural marsh expansion with sea level rise, measures to protect the land upland of the salt marsh between Lafayette Road and Depot Road in Hampton Falls from development are recommended. Due to the generally high level of development in the surrounding upland, this area was selected because it is a forested upland with few barriers to impede the landward migration of the marsh in response to increased flooding.
13. Hampton Falls River – A dam currently exists on the Hampton Falls River at the route 1 crossing. High quality habitat exists upstream; therefore, exploration of opportunities for dam removal or installation of fish passage is recommended. Due to the abundance of dams along the main stem of this system, evaluation of the feasibility of restoring fish passage to the upstream reaches is also recommended.
14. Mill Creek – The salt marsh-upland border around the tidal portion of Cains Brook (i.e., Mill Creek) contains multiple stands of *Phragmites*. Current research at the University of New Hampshire is evaluating *Phragmites* removal techniques in this area. Based on the conclusions of the research, it is recommended that the stands of *Phragmites* at this site be removed to improve the habitat value of the site and prevent the further spread of *Phragmites*.
15. Noyes Pond Dam – The Noyes Pond Dam and the Cains Brook Dam are recommended for removal to restore hydrologic connectivity and access to upstream fish habitat in this system. To increase success of fish use, measures to mediate water quality are also recommended. It should be noted that varying perspectives exist regarding the management of these dams and that the recommendation to remove the Noyes Pond Dam is contrary to those outlined in the watershed management plan prepared by the town of Seabrook (Waterfront Engineers and Appledore Engineering 2006).
16. Cains Brook near Home Depot/Lafayette Road, Seabrook – To combat erosion at this site and improve riparian habitat, planting efforts and shoreline stabilization are recommended along the banks of Cains Brook to restore the riparian buffer.

Blackwater River subwatershed (Figure 21)

17. Sea level rise protection - Protective measures are recommended for the area landward of the salt marsh west of Worthley Ave., Seabrook, NH and Seabrook Road, Salisbury, MA due to the potential adaptive benefits as a result of sea level rise. This expanse of vegetated upland is recommended for protection to provide a buffer and to allow for natural marsh expansion with sea level rise.
18. Old County Road, Salisbury, MA – Several small culverts under Old County Road restrict tidal flow to the marsh upstream which is currently dominated by *Phragmites*. It is recommended that the existing culverts be replaced with a larger culvert. In addition to culvert replacement, the area upstream of the degraded marsh is former salt marsh that was filled; this area is recommended for fill removal to lower the elevation to mean high tide. More details on this site are available in MA

CZM's Great Marsh Coastal Wetlands Restoration Plan (MA CZM 2008; tidal restriction - site 353*; fill removal – site 6*).

19. Parking lot at intersection of Northern Blvd and Beach Road, Salisbury, MA. -This site includes an area of fill adjacent to a stand of *Phragmites*. Excavation of fill and *Phragmites* at this site is recommended to increase tidal inundation to the area and return it to salt marsh. (MA CZM 2008; site 8*)

Dunes are most effective when contiguous; therefore, it is recommended that a continuous dune line be restored throughout the Hampton, Seabrook and Salisbury dune system to receive maximum ecological function, particularly in terms of wind and shore protection. To achieve this:

20. Establish (or continue where they exist) sand fencing programs or dune replenishment and planting programs along the seaward side of all properties to reestablish a continuous dune line.
21. Replenish sand to the beach access area on the NH/MA border along Atlantic Ave to rebuild the dunes. Install educational signs to prevent further trampling.
22. Explore methods of sand addition to maintain the backdune in Seabrook (west of route 1).
23. Survey interdune regions throughout the coast as well as the Seabrook backdune for invasive species and develop plans for invasive species removal where they are present.
24. Continue efforts to limit private pathways for beach access through dunes south of Hooksett Street, Seabrook, NH, through Salisbury, MA, with educational signs, structural fencing and enforcement to divert pedestrians to municipal pathways. Efforts currently exist in both Seabrook, NH and Salisbury, MA. Conduct workshops on the ecological importance of dunes for property owners to educate them on dune function and discuss property owner concerns.
25. Install snow fencing to create a band of foredune between Tilton and Pembroke Streets, Seabrook. Explore opportunities for the beneficial use of washover sand on roadways and dredge spoil to replenish dunes as well as revegetation projects.

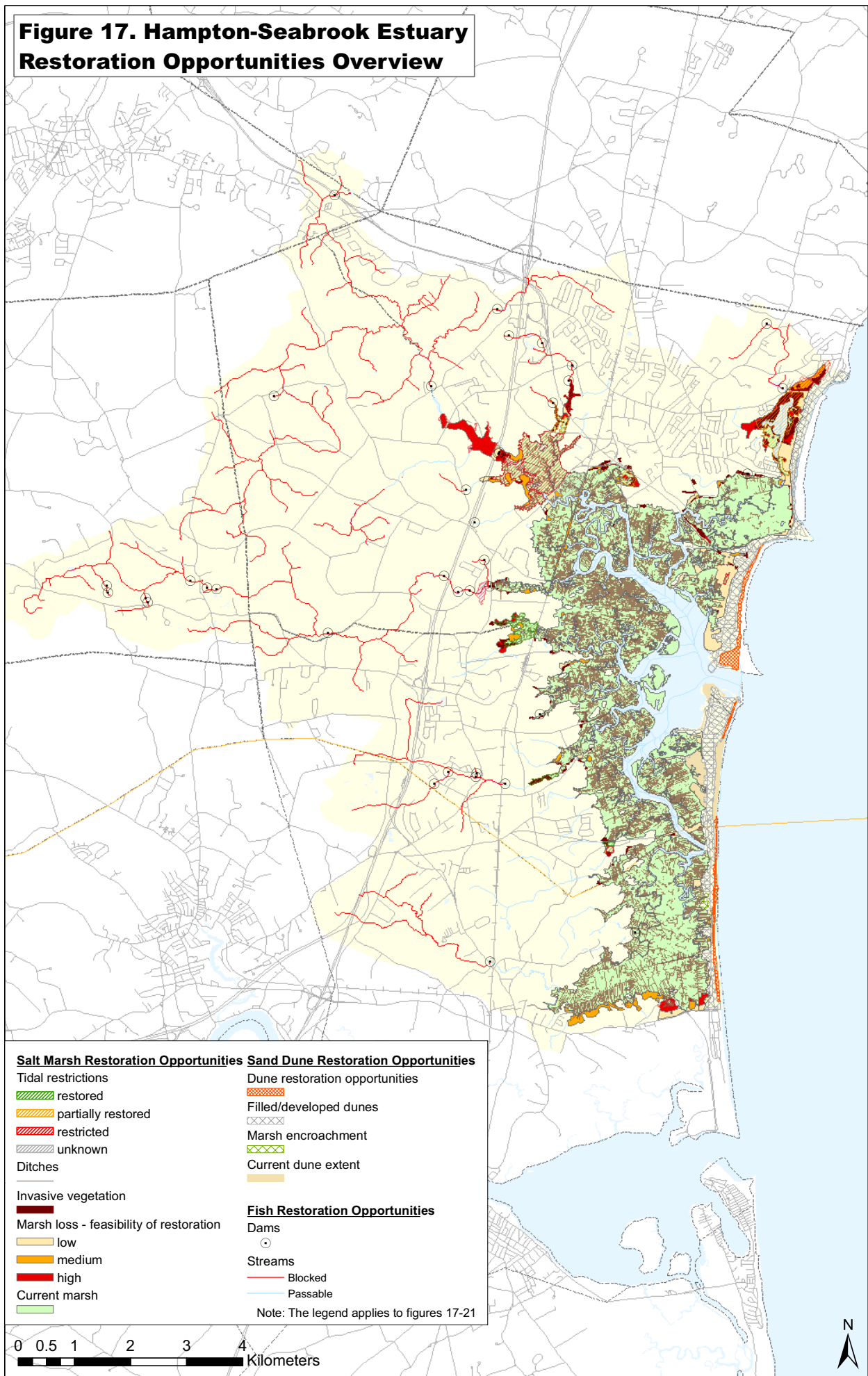
* Sites shown in Salisbury, MA are potential restoration opportunities identified in the Great Marsh Coastal Wetlands Restoration Plan (2008) prepared by the Massachusetts Office of Coastal Zone Management's Wetlands Restoration Program. While these sites may offer opportunities for coastal wetlands restoration, actual restoration potential, landowner interest, and overall project feasibility have not been confirmed.

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Figure 17. Hampton-Seabrook Estuary Restoration Opportunities Overview



**Figure 18. Hampton-Seabrook Estuary Restoration Opportunities
Tide Mill Creek - Meadow Pond**

Numbers on the map correspond to restoration opportunities highlighted in the text.

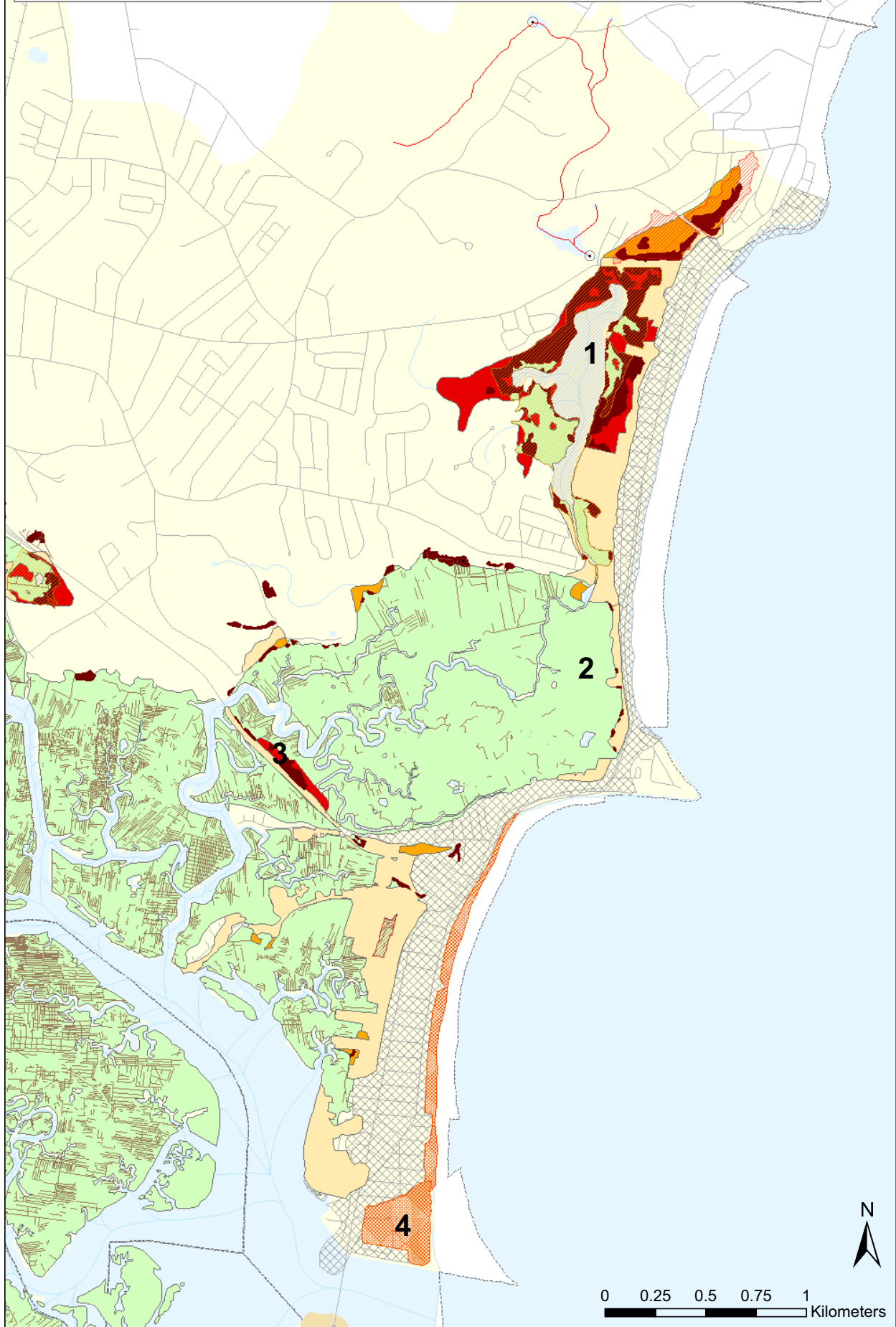
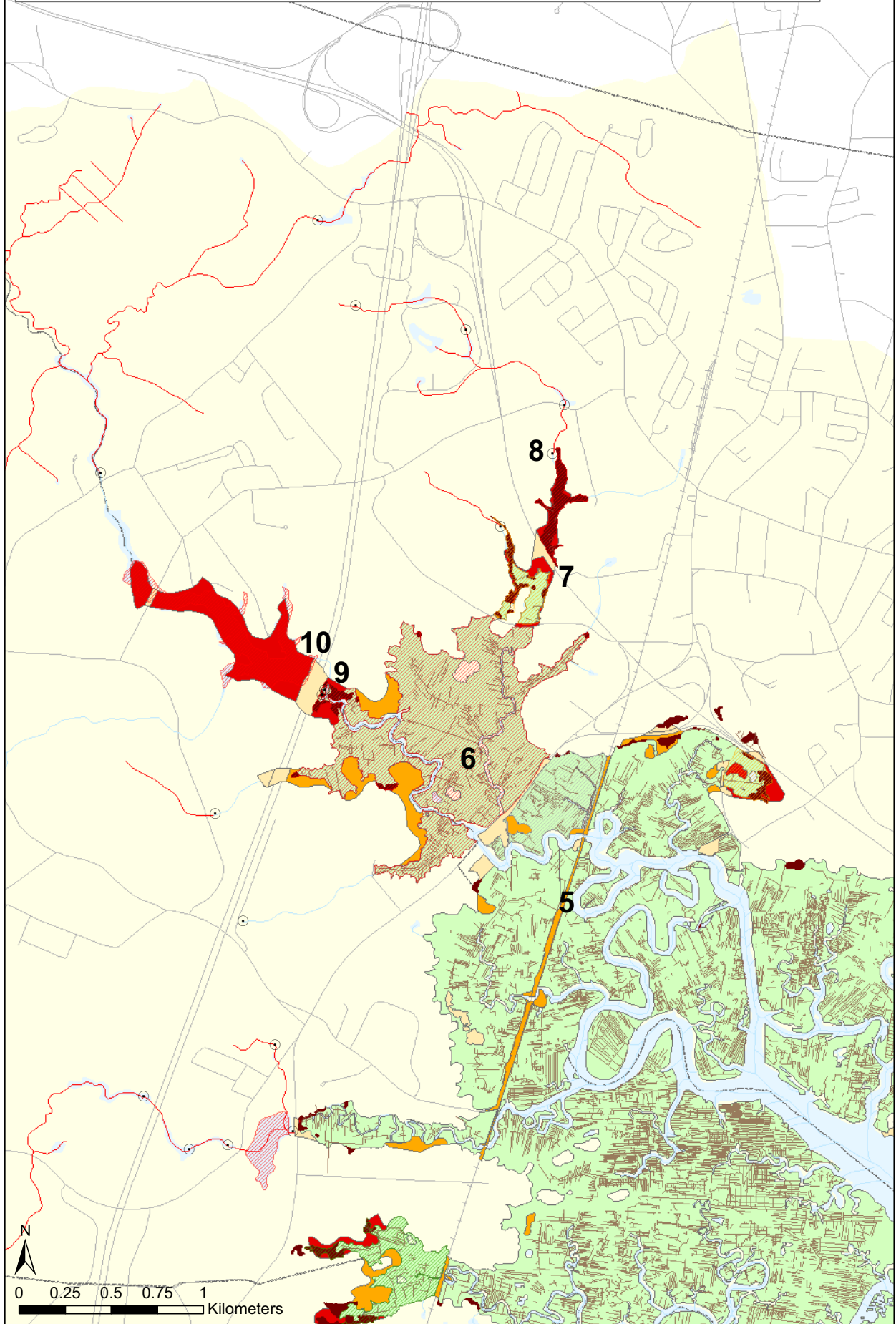


Figure 19. Hampton-Seabrook Estuary Restoration Opportunities Taylor River-Drake's River

Numbers on the map correspond to restoration opportunities highlighted in the text.



**Figure 20. Hampton-Seabrook Estuary Restoration Opportunities
Hampton Falls River-Browns River-Cains Brook**

Numbers on the map correspond to restoration opportunities highlighted in the text.

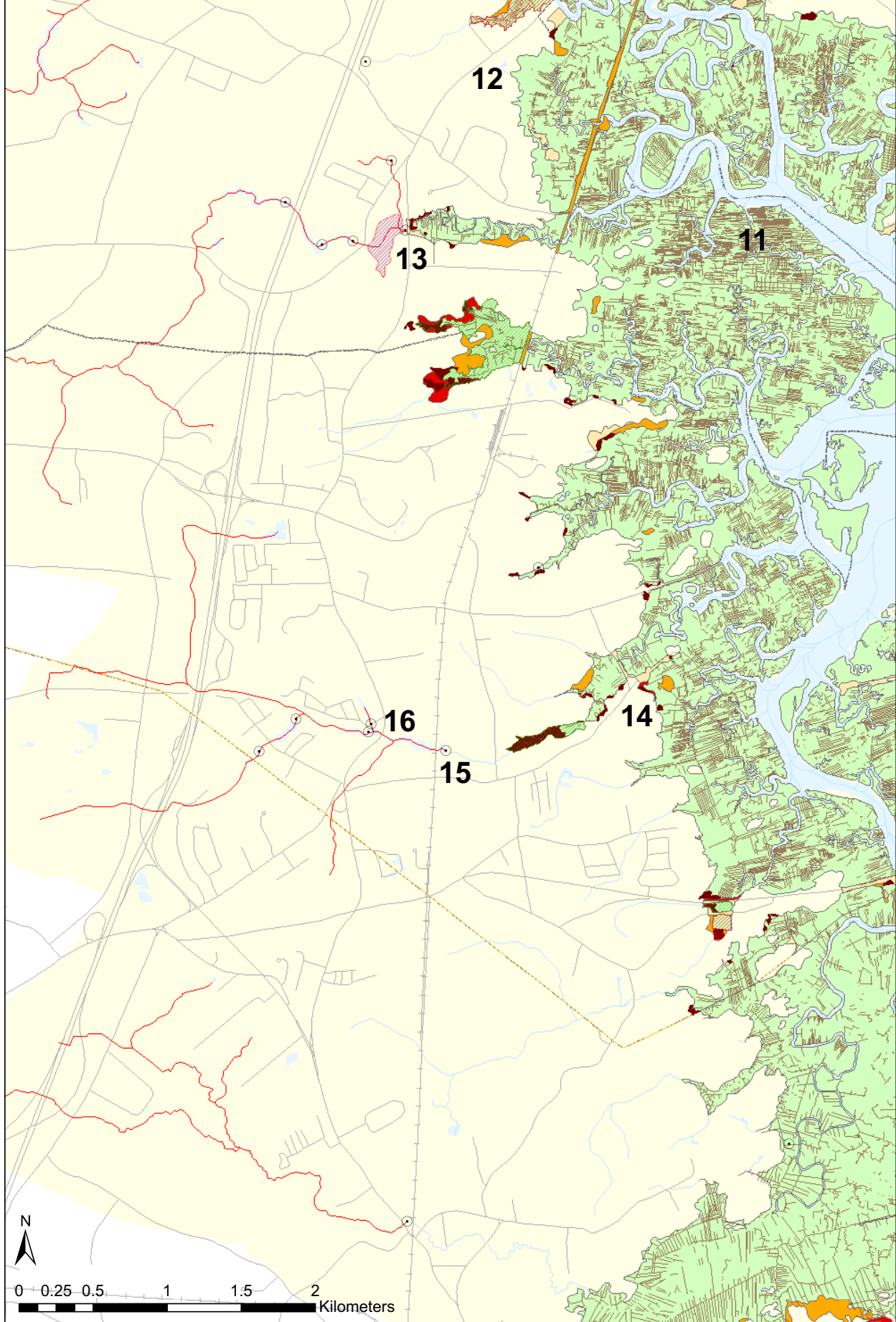


Figure 21. Hampton-Seabrook Estuary Restoration Opportunities Blackwater River

Numbers on the map correspond to restoration opportunities highlighted in the text.

