A1. Title and approval sheet

Quality Assurance Project Plan
for
Geographic Information System Analysis of Projected Salt Marsh Expansion with Sea Level Rise in Buzzards Bay

Workplan task 13, EPA Cooperative Agreement CE-96144201-1

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September 12, 2013

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Acknowledgments
The principle authors of this plan are Joseph Costa and John Rockwell of the Buzzards Bay National Estuary Program and David Janik of Massachusetts Office of Coastal Zone Management.

A2. Table of Contents

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Section A. PROJECT MANAGEMENT ELEMENTS

This section describes the design and implementation of the project. Implementation of these elements will ensure that appropriate methods for sampling, measurement and analysis, data collection or generation, data handling, and QC activities are employed and are properly documented.

A3. Distribution list

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Additionally, copies will be on file with the Massachusetts Office of Coastal Zone Management, 251 Causeway St., 8th Floor, Boston, MA 02114

A4. Project and task organization

Activities for this project will involve principally an analysis of GIS datasets. The three project leads will develop the necessary GIS coverages and will prepare the final project report and maps for each municipality.

Some fieldwork will be undertaken by the BBNEP wetland specialist to confirm plant species that coincide with features evident on aerial photographs. In these cases, the wetland specialist will use a Trimble GeoXT unit that has a nominal 0.5-meter horizontal accuracy. This fieldwork will not be used to define marsh boundaries for the purposes of the study, but to show sample vegetation types at the calculated high tide line, and for case studies on the application of the maps generated by this study.

Project Manager: Joseph Costa, Buzzards Bay National Estuary Program (NEP) Executive Director, is the overall project manager, lead principal investigator for the project, and is responsible for analysis and integration of datasets, communication, project management, maintaining and distributing the QAPP, and project reporting. He will develop GIS spatial coverages representing changes in the flood zone.

GIS Analyst: John Rockwell, Buzzards Bay NEP Wetland Specialist, will develop GIS spatial coverages representing physical boundaries of salt marsh units, which will be used as boundaries in the calculation of areas defining their potential expansion inland because of sea level rise. He will also conduct GPS field verification to document vegetation types at selected sites at the high tide elevation, and to document or evaluate the location of transition zones between salt and freshwater systems. This information will be used to evaluate the general reliability of calculating salt marsh boundaries based on high tide line elevations calculated using the VDatum tidal elevation model (version 3.2, March 2013) and the methods described here.

Quality Control Officer: David Janik, Massachusetts Coastal Zone Management, South Coastal Regional Coordinator, is the quality control officer for this project, and will ensure that the protocols described here are adopted.

A5. Problem definition and background

Coastal salt marshes are an important habitat and nursery for many coastal marine species of plants, aquatic and terrestrial vertebrates, and invertebrates. Other functions provided by salt marsh ecosystems include storm damage prevention, prevention of pollution, protection of marine fisheries and wildlife habitat, and a source of primary production carbon that is the basis of coastal food webs. Salt marshes also contribute to aesthetic values of the coast. Historically, many salt marsh areas in Buzzards Bay have been filled or otherwise adversely affected by human activities.

Since the end of the last ice age, sea levels have risen hundreds of feet, and salt marshes have migrated inland in concert with the coastline. In recent centuries, it is believed that most salt marshes in protected areas have been able to accrete vertically to keep pace with rising sea level that stands at roughly 10 inches per century relative to the local rate. With global warming, the rate of sea level rise may increase. If vertical accretion within salt marshes cannot keep pace with rising sea levels, and if they cannot migrate inland, they will be lost.

Besides the potential threat of increased rates of sea level rise and their ability to accrete sediments to keep pace, two impairments are common in surviving salt marshes. First, many salt marshes have had tidal exchange with the ocean restricted by road construction and undersized culverts. Second, road construction, raised fill areas with steep grades, bulkheads, and similar features have raised adjoining land elevations to such an extent that a boundary is created that prevents further inland migration of salt marshes under the sea level rise scenarios.

For this study, we will estimate the predicted landward expansion of the high marsh boundary with sea level rise based on a simple "bath tub" model approach using a methodology recommended by NOAA, with some modification[1]. This approach is based on modeled tidal datum elevations in NOAA's VDatum model to estimate local tidal datum elevations that approximate the existing high marsh boundaries around Buzzards Bay[2]. The mapping process used is also similar to the approach used by the NOAA Coastal Services Center to map sea level rise inundation for their Sea Level Rise Viewer[3]. The expansion of the boundaries of the marsh with sea level rise will be based on a bathtub model approach using the calculated high tide line elevation, applied to LiDAR[4] digital elevation model data.

A5.1. Definition of high marsh boundary

New England salt marshes are typically classified into three intertidal zones: low, middle, and high marsh based on the assemblage of plant species found in each (e.g., Redfield 1972; Nixon 1982; Bertness, 1992; Donnelly and Bertness 2001). The plant species assemblage in each of these zones is defined by the frequency of tidal flooding and the average inundation time. In Buzzards Bay, the low marsh is dominated by cord grass, *Spartina alterniflora*, and begins roughly at mean sea level (MSL).

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[1] NOAA (undated). "Detailed methodology for mapping sea level rise marsh migration:" available at www.csc.noaa.gov/slr/viewer/assets/pdfs/Marsh_Migration_Methods.pdf. Last accessed 29 May 2013. See also Myers (2005).

[2] VDatum 3.2 (2013) uses GEOID12a, whereas the FEMA 2006 LiDAR uses GEOID3 and the 2010 Northeast LiDAR data GEOID09. Because the upper portions of Buzzards Bay are higher by 3.5 cm in GEOID12a, grading to less than 1 cm in lower Buzzards Bay, these differences in the NAVD88 elevations will need to be accounted for.

[3] See NOAA CSC 2011.

[4] Light detection and ranging (also abbreviated LiDAR and LADAR) is an optical remote sensing technology that can measure the distance to a target by illuminating it with pulse of light from a laser.

The middle marsh area, occurring roughly between mean high water (MHW) and mean high higher high water (MHHW) is dominated by *Spartina patens*, *Salicornia* spp., *Distichlis spicata,* and *Juncus gerardii*. The high marsh environment occurs above MHHW, and vegetation includes mid-marsh species as well as the invasive *Phragmites australis*. The transition between the high salt marsh and upland areas include certain characteristic species such as the high tide bush *Iva frutescens*, and switch grass, *Panicum virgatum*. Salt marshes may also grade into freshwater wetlands. The actual real world elevation of all these boundaries with respect to local tidal datums depends on numerous factors ranging from fresh water inputs to levels of eutrophication (Bertness et al. 2002, 2009; Silliman and Bertness, 2004).

Under the Massachusetts Protection Act regulations (310 CMR 10.0), a salt marsh is defined as "a coastal wetland that extends landward up to the highest high tide line, that is, the highest spring tide of the year, and is characterized by plants that are well adapted to or prefer living in, saline soils. Dominant plants within salt marshes are salt meadow cord grass (*Spartina patens*) and/or salt marsh cord grass (*Spartina alterniflora*)."

In federal regulations (33 U.S.C. 1344, Regulatory Program of the US Army Corps of Engineers, Part 328.3), the "high tide line"(sometimes called the annual high tide) is defined as "the line of intersection of the land with the water's surface at the maximum height reached by a rising tide. The high tide line may be determined, in the absence of actual data, by a line of oil or scum along shore objects, a more or less continuous deposit of fine shell or debris on the foreshore or berm, other physical markings or characteristics, vegetation lines, tidal gages, or other suitable means that delineate the general height reached by a rising tide. The line encompasses spring high tides and other high tides that occur with periodic frequency but does not include storm surges in which there is a departure from the normal or predicted reach of the tide due to the piling up of water against a coast by strong winds such as those accompanying a hurricane or other intense storm."

Not explicit in the state and federal regulations is the fact that the high tide line refers to the current high tide line during the recent year, and not an average for the current tidal epoch. The tidal definitions used in this tidal studies and various regulations are summarized in Table 2, which also shows Newport tidal datum elevations. Most of Buzzards Bay has tidal characteristics similar to that of the Newport Tidal station.

Table 2. Elevations of Newport Tidal Datums (1) converted to NAVD88 GEOID 12a

Datum Abbreviation	Range Ft	Elev. Ft NAVD88	Description
HTL for 2013 (salt marsh reg. boundary)		3.06	high tide line (aka annual high tide)
MHHW (typ. *S. patens* monoculture)		1.81	mean higher high water
MHW		1.57	Mean High Water
DTL		-0.11	Mean Diurnal Tide Level
MTL		-0.16	Mean Tide Level
LMSL (typ. *S. alterniflora* edge)		-0.30	Local Mean Sea Level
MLW		-1.90	Mean Low Water
MLLW		-2.04	Mean Lower Low Water
GT	3.85		Great Diurnal Range(MHHW-MLLW)
MN	3.47		Mean Range of Tide (MHW-MLW)

As reported at: http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8452660 Newport, RI&type=Datums, Accessed 24 May 2013.

For this study, a practical definition of the upper salt marsh boundary is needed. Based on field observations matched to LiDAR data around Buzzards Bay, the Buzzards Bay NEP has determined that the annual high tide or high tide line (HTL) of larger non-tidally restricted salt marshes tends to coincide with a transitional vegetation zone between marsh species and upland species (e.g. *Iva fructens* grading to cedar uplands as evident in aerial photographs). Areas dominated by *Spartina patens* (i.e. the high marsh) tend to occur somewhere between the MHHW elevation and the HTL elevation. Areas above the HTL are generally easy to distinguish on aerial photographs due to the presence of cedar trees and other shrub and tree vegetation types.

Rather than attempt to make an ecological determination of the boundary of areas dominated by *Spartina* species, which tend to occur somewhere between the MHHW and HTL and would require extensive fieldwork, for this study we settled upon a calculated HTL elevation (using VDatum and local NOAA Tidal station records). The selection of the HTL elevation as the definitive salt marsh boundary ensures consistency with the definition of the salt marsh boundary under state regulations, and matched the federal definition of the boundary of tidelands.

However, we have also determined that the predicted HTL using the methods described here is not a good predictor for defining marsh boundary in the upper portions of large estuaries. This may be because VDatum does not model well these upper estuary areas. In these instances it would be incorrect to assume that the VDatum derived HTL elevation at the mouth of these estuaries matches the HTL elevation in the upper estuary. For example, in the uppermost portions of the Acushnet River and East Branch of the Westport River, the apparent marsh boundary elevation is 0.5 to 0.7 feet lower than the HTL elevation at the mouths of the respective estuaries. In these environments, if the HTL elevation near the mouth of the bay does not coincide with marsh boundaries in the upper estuary, we will instead use a LiDAR elevation that best coincides with salt marsh boundaries evident on aerial photographs. These elevations will be used as a starting point, and 1- 2- and 4 feet will be added to those revised elevations for the sea level rise scenarios.

Some fieldwork will also be conducted for this analysis. However, this fieldwork will not be used so much to set marsh boundary, but rather to document vegetation types (through photography) near the HTL elevation at selected sites to evaluate the overall reliability of the approach. This fieldwork will also be used to document fresh and brackish wetland species at selected tidally restricted marshes to illustrate how the GIS data generated by this study can be used. In a few estuaries where there are apparent discrepancies between VDatum and salt marsh vegetation in unrestricted areas, a new VDatum elevation will be selected based on best professional judgment using aerial photographs and LiDAR data.

A6.1. Task Description Overview

This geospatial project will use existing data from a source external to the Buzzards Bay National Estuary Program[5]. These datasets will be manipulated to create new maps to be used for planning purposes. The overall strategy for this effort is to demarcate the high tide line (HTL) elevation (also

[5] The 2006 LiDAR coverage was obtained from FEMA and was used in part to prepare the updated Bristol and Plymouth County FIRMs (CDM Smith, 2008). The 2010 LiDAR coverage was collected through the Northeast LiDAR Project and covers Barnstable County. These LiDAR data exist as bare-earth digital elevation models (DEMs) in the form of triangular irregular network (TIN) or Imagine raster files. In general, the elevation precision of the LiDAR data is 1 cm, but the accuracy is generally approximately 6 inches over the entire southeast study area. The relative accuracy over a small geographic area along the same flight path is considerably better (USGS, 2004). The two data sets are sufficiently consistent for the purposes of this study.

known as the annual high tide or AHT) in each available LiDAR dataset. This calculated elevation will be used to define the salt marsh boundary in the LiDAR data sets. We will extrapolate the expansion of this boundary under the various sea level rise scenarios.

The high tide line will be calculated based on the VDatum model[6] and supplemented by NOAA tidal predictions for the 2013 annual high tide[7]. The VDatum tidal model dataset used in this study is the definitive tidal model used by NOAA for general sea level rise studies. VDatum predicts mean higher high water (MHHW) elevations, but does not predict the somewhat higher high tide line elevation. The difference between these two elevations has been modeled by the Buzzards Bay NEP as described in the sections below. The Buzzards Bay NEP has already modeled the high tide line elevation for all of Buzzards Bay. This high tide line will be applied to the LiDAR data sets to create polygon boundaries for existing marshes. This work will take two months and will be completed in the fall of 2013.

The methods adopted here are similar to the aforementioned NOAA model[8] with one important exception. We will only map the inland migration of upper marsh boundary; we make no estimates about the ability of marshes to be able to accrete with different rates of sea level rise.

It is worth stressing that no field data is needed to define marsh boundary under this approach. We will, however, conduct field visits during the fall of 2013 with cameras and GPS units, in different parts of Buzzards Bay. These field visits will be used to document vegetation types at the high tide line elevation at selected locations in different parts of Buzzards Bay. This information will not be used to define the high tide line boundary, as that elevation is based strictly on applying the calculated high tide line elevation to the LiDAR data set. Rather, these field visits and photographs will be used for general informational purposes, and to identify areas where fresh or brackish wetland species exist within the expected salt marsh boundary. These field investigations are not meant to be comprehensive. Rather, they will be used to provide examples of how the results of this study can be applied to investigations of tidally restricted salt marshes and salt marsh expansion.

A6.1.1. Defining marsh boundaries in the context of LiDAR datasets

The analysis will be undertaken using ArcGIS® software by Esri[9]. As noted above, the Buzzards Bay NEP has already calculated the high tide line (HTL) elevation for the coastline of Buzzards Bay, and this elevation will be used to define the boundary of salt marshes. Although the calculation of the elevation of the HTL around Buzzards Bay is complete, we provide below a detailed explanation of the methods used to define the HTL so that underlying modeling assumptions are understood and can be transferred to other studies. Applying this elevation to the LiDAR digital elevation model datasets will take 2 months and will be complete by November 2013.

[6] VDatum uses model grid files for each tidal datum in Table 2 (excluding annual high tide) for the Massachusetts to Maine Region based on NOAA CO-OPS tidal station data, adjusted to the current epoch. VDatum interpolates these values and accounts for GEOID and datum conversion to enable conversion of all key local tidal datums to NAVD88 GEOID12a.

[7] Available at http://tidesandcurrents.noaa.gov/tide_predictions.shtml?gid=37

[8] "Detailed methodology for mapping sea level rise marsh migration" see footnote 1.

[9] ArcGIS® software by Esri (ArcMap desktop versions 9.3 and 10.1) will be used to define salt marsh boundaries to meet the High Tide Line elevation, and through expansion of these boundaries based on a bathtub approach. Additional analysis will be completed in spreadsheets using pivot table functions.

Real world tidal elevations and tidal ranges vary around Buzzards Bay. Based on a review of LiDAR data and field observations in 2013 (including observations of king tides in June), the Buzzards Bay NEP determined that annual high tide elevation is a reasonable approximation of the high marsh transitional zone to upland species in non-tidally restricted areas. However, the high tide line (=annual high tide) is not an output function in the NOAA VDatum model, so the elevation must be approximated.

Data for the HTL is available for 20 tidal stations in and around Buzzards Bay. For these elevations, we used the specific predicted annual high tide elevations above the local tidal datum as reported by NOAA for June 23, 2013[10]. Based on Guidance from NOAA, we omitted two anomalous station outlier values[11]. We used as a starting point the real world elevations of the mean higher high water elevation as calculated by the VDatum model (Fig. 1). Using the HTL elevations above MHHW for the 18 tidal stations in and around Buzzards Bay, we interpolated these values using Spatial Analyst[12] to generate a model of the HTL elevation above MHHW for Buzzards Bay (Fig.2). These elevations were added to the elevations of MHHW in Fig. 1 to calculate the real world elevation of the annual high tide. It is worth noting that precision of the HTL adjustment exceeds the precision of individual tidal stations (harmonic stations have an assumed accuracy of 0.1 foot, subordinate stations have an assumed accuracy of 0.25 foot), but collectively these station values provide the basis for establishing the elevation of the HTL above MHHW across Buzzards Bay. These limitations will be discussed in the final report.

While the LiDAR datasets and VDatum all use the same datum (NAVD88), each uses a different GEOID model. We used for this study, the most recent version of VDatum (version 3.2, March 2013), which employs GEOID12a, whereas the 2006 FEMA LiDAR dataset (the western shore of Buzzards Bay) uses GEOID3, and the 2010 Northeast LiDAR dataset (eastern shore of Buzzards Bay through Butler Cove, just south of Buttermilk Bay) used GEOID9. These GEOID differences must be accounted for. More specifically, to select the correct LiDAR elevation corresponding to a specific VDatum elevation, the elevations shown in Figs. 3 and 4 must be subtracted. As shown, the GEOID12a to GEOID9 adjustment is trivial, but the GEOID12a to GEOD3 is more significant, especially in the southern areas of Buzzards Bay.

One additional adjustment must be made to account for the fact the VDatum and NOAA predicted tides are based on data from the last 19-year tidal epoch (1983-2001), and thus represent the mid-point (1992-1993) average conditions. Because there have been 20 years of sea level rise since 1993, we added 0.17 feet (the estimated sea level rise for our area based on Newport and Woods Hole average SLR rates) to the HTL calculation to estimate the real world elevation of the HTL in 2013.

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[10] Available at http://tidesandcurrents.noaa.gov/tide_predictions.shtml?gid=37. Last accessed 24 June 2013.

[11] Todd Ehret (NOAA Center for Operational Oceanographic Products and Services), pers. comm. The Clarks Point station was omitted because it was had an anomalously low HTL above MHHW compared to surrounding stations. This anomalous value may be related to the fact that it was based on an older short term data set (only five months of tidal records in 1976). The Quicks Hole station data had an anomalously high HTL elevation above MHHW, and was omitted for several reasons. This station is on the south side of a peninsula at the boundary of Buzzards Bay and at the nexus of two tidal regimes. The tidal transition zone in these areas is quite narrow, however, the GIS point interpolation tool used to create the HTL elevations in this study gives this single point too much weight across central Buzzards Bay. To avoid the bias generated by this outlier, it was omitted.

[12] ArcGIS 10.1 tool called "interpolation spline with boundary."

Finally, we note that both LiDAR datasets are expressed as bare earth digital elevation models. Various LiDAR studies of salt marshes have found that reported bare earth LiDAR elevations must be adjusted for grass canopy. This is because, even during winter time when LiDAR data is collected typically, dead *Spartina* spp. blades form a matted dead might still be 3-25 cm thick (e.g. Schmid et al., 2011; Hladik and Alber, 2012). However, because the HTL boundary is typically well above the *Spartina* monoculture, and these transitional areas (often at the edge of small coastal banks) typically have species where bare earth is evident at the time of LiDAR surveys, we made no adjustment for *Spartina* canopy in this study.

Based on the methods and studies summarized above, the calculated annual high tide elevation in the two respective LiDAR datasets are shown in Fig. 5 (=Fig. 1 values + Fig. 2 - [Fig. 3. or Fig. 4] + SLR increase since 1993).

A6.1.2. Creation of salt marsh expansion zones with sea level rise scenarios

We assumed that the boundary of salt marsh systems in non-tidally restricted areas to be equal to the estimated annual high tide elevations shown in Fig. 5. For each salt marsh system around Buzzards Bay we applied the elevation shown in Fig. 5, and to that elevation we added 1-, 2-, and 4- ft to project the corresponding sea level rises. For example, in West Falmouth, a marsh boundary elevation of 3.2 feet (LiDAR elevation based on HTL elevation and aforementioned adjustments) was selected, and land areas bounded 4.2, 5.2, and 7.2 feet in the LiDAR bare earth DEMs was calculated.

The selected 1-, 2-, and 4-ft elevation increases in this study were chosen as convenient management elevation markers for local municipal planners and resource managers. The relative sea level rise rate documented for Woods Hole, MA has been 10.3 inches per century since 1930[13]. The IPCC (2007) consensus range for sea level rise, applied to this region, is 1 to 4.5 feet by year 2100. However, some other studies with alternative scenarios with more expanded Greenland and Antarctic glacier melting, or changes in the North Atlantic gyre may result in higher local sea level rise rates. We thus leave open ended how quickly the 1, 2, and 4-ft elevation increases may occur.

The HTL elevation is a regulatory boundary, and represents the assumed approximate ecological boundary of salt marsh species. However, in tidally restricted areas, vegetation at the HTL elevation may in fact be composed of brackish or freshwater wetland species. In this study, we will demarcate these non-salt marsh vegetation areas to identify sites that may benefit from the removal of tidal restrictions. This information will represent an improvement over the analysis contain in the 2002 *Atlas of Tidally Restricted Salt Marshes in the Buzzards Bay Watershed Massachusetts*. This information (maps of non-marsh vegetation below the HTL elevation) can be used to prioritize tidally restricted sites for restoration.

The findings of this study will be summarized in a report and maps for each studied site, the entire bay, and for evaluated marshes in each municipality. These documents are expected to be used by both the state and municipalities for general planning purposes related to climate adaptation and to help prioritize salt marsh protection, restoration, and land protection efforts for each community.

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[13] Data available at http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8447930. This is the average rate for the period 1932 to 2006.

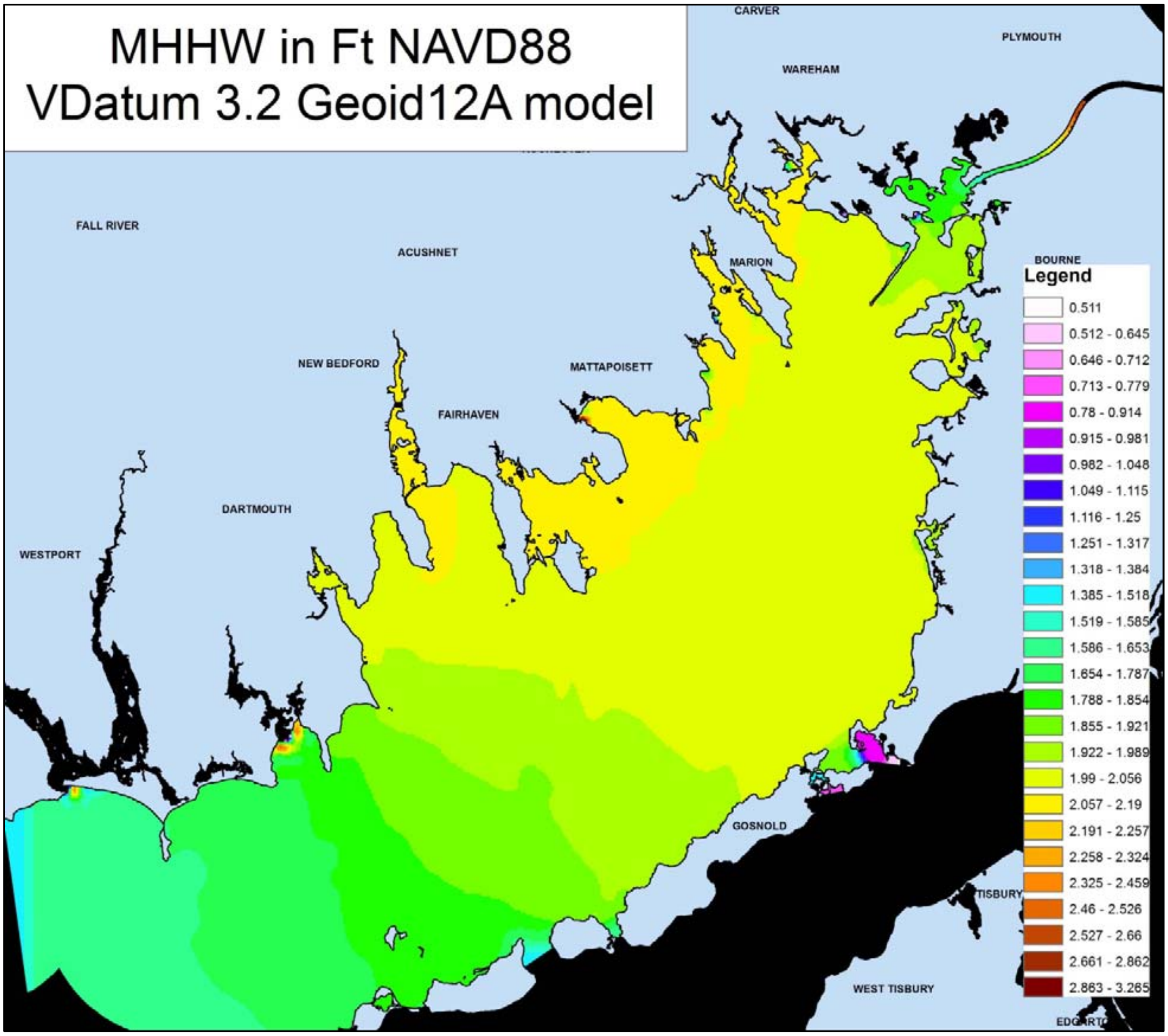

Fig. 1. Estimated MHHW elevations in Buzzards Bay as NADD88 ft (GEOID12a, VDatum 3.2, March 2013). Embayments shaded black have no prediction in VDatum.

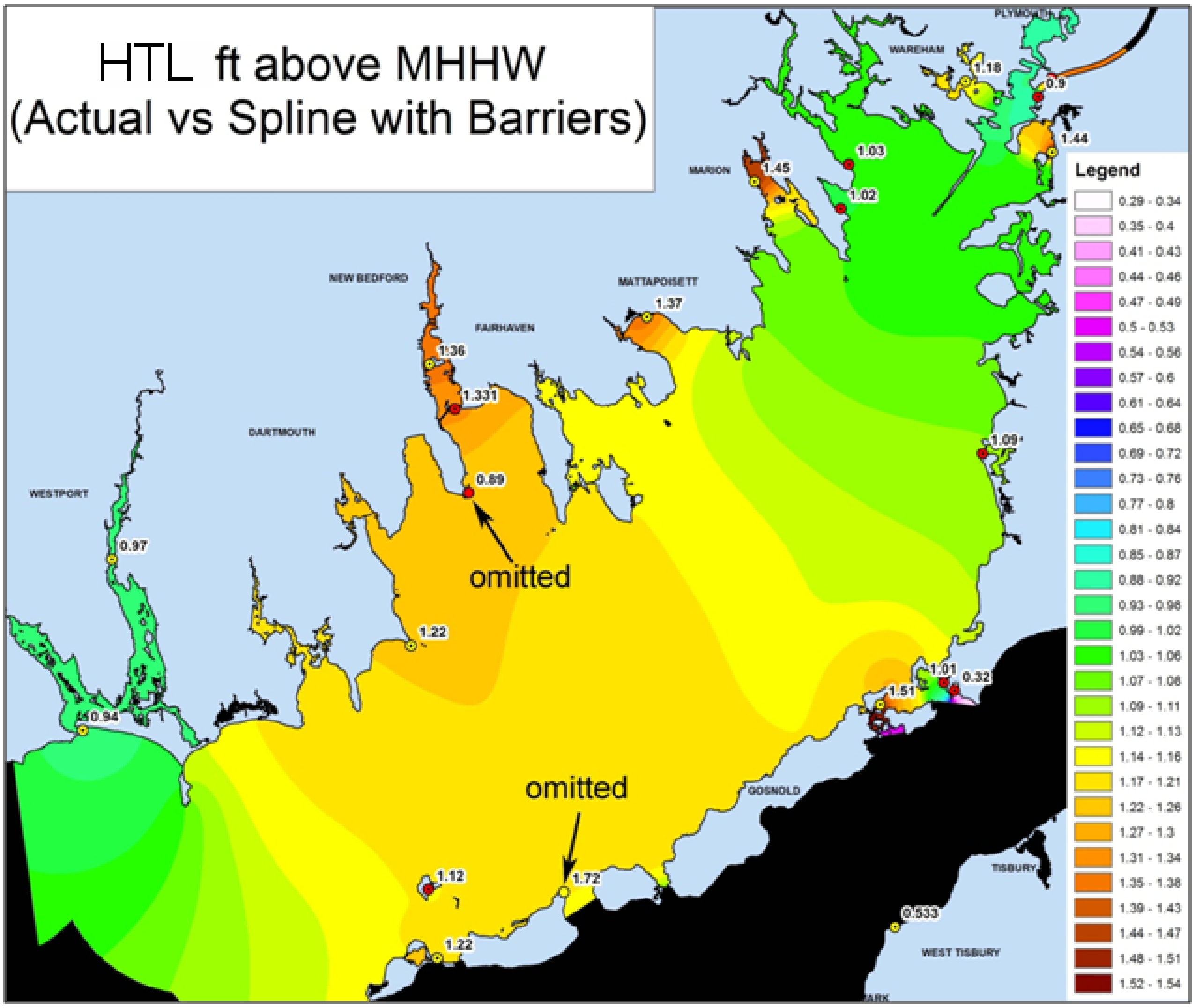

Fig. 2. Estimated annual high tide elevation above MHHW. The bay and embayments are shaded to show the modeled elevation of the high tide line above MHHW according to the key on the right (elevations in feet). This model surface was calculated using the 18 data points shown, which represent the actual NOAA tidal datum station locations, and the actual elevation of the high tide line above MHHW at those stations. All tidal elevations were converted to NAVD88 ft GEOID12a using VDatum 3.2 (March 2013). The modeled base map raster was generated using these data points with a Spline interpolation using the coast as a boundary using Spatial Analyst. One point on the Rhode Island coast was used but is not shown on the map. See text for additional explanation on omitted values.

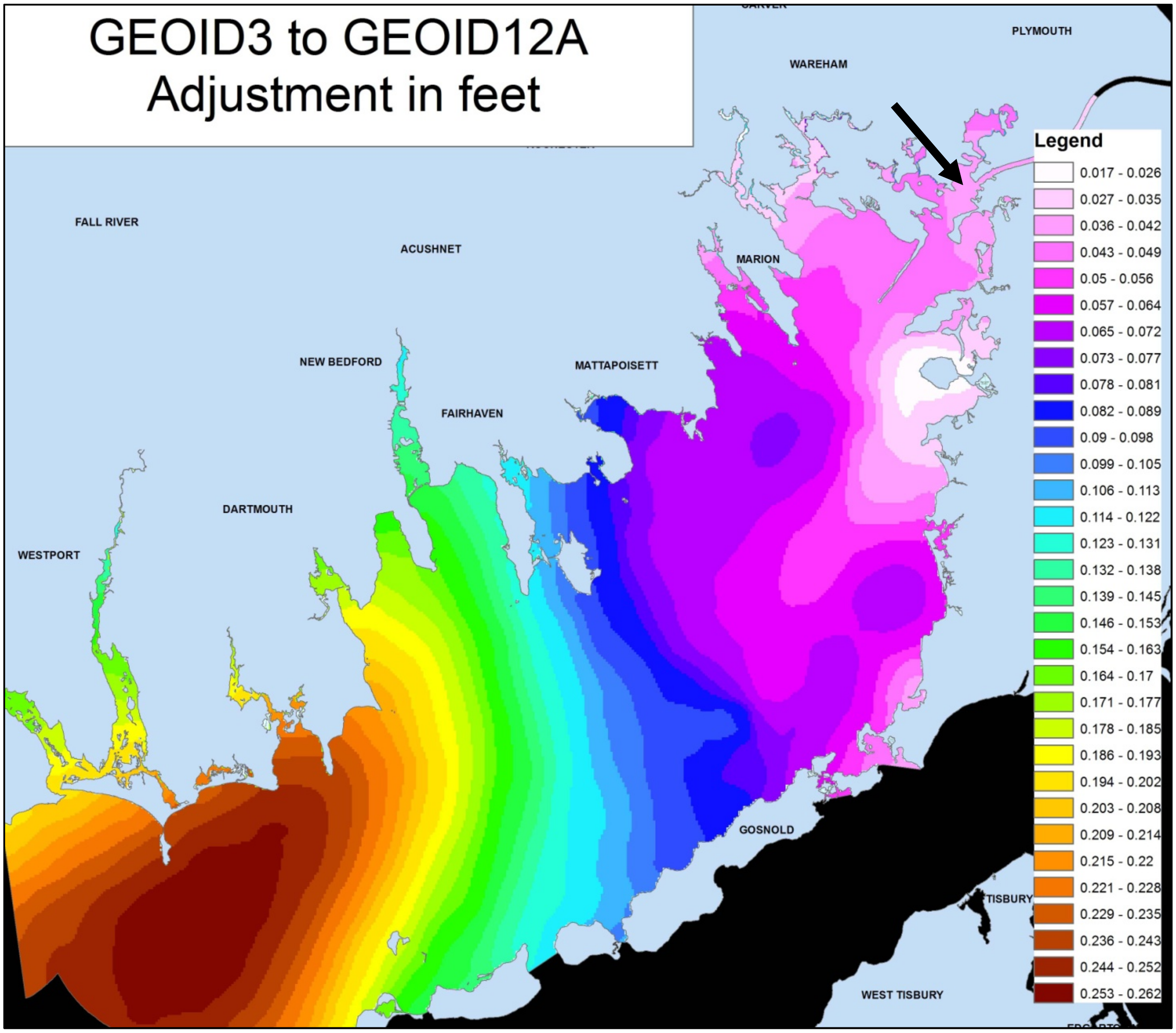

Fig. 3. Adjustment in converting NAVD88 GEOID3 elevations in feet to NAVD88 GEOID12a elevations as reported in VDatum 3.2 (March 2013). The LiDAR datasets does not use the same GEOID elevations as VDatum. This figure shows the correction factor needed for the 2006 FEMA LiDAR dataset. This figure is relevant only for the west side of Buzzards Bay (Westport to the arrow in Wareham). The elevations represented by the color key must be subtracted from VDatum elevations to obtain reported LiDAR elevations.

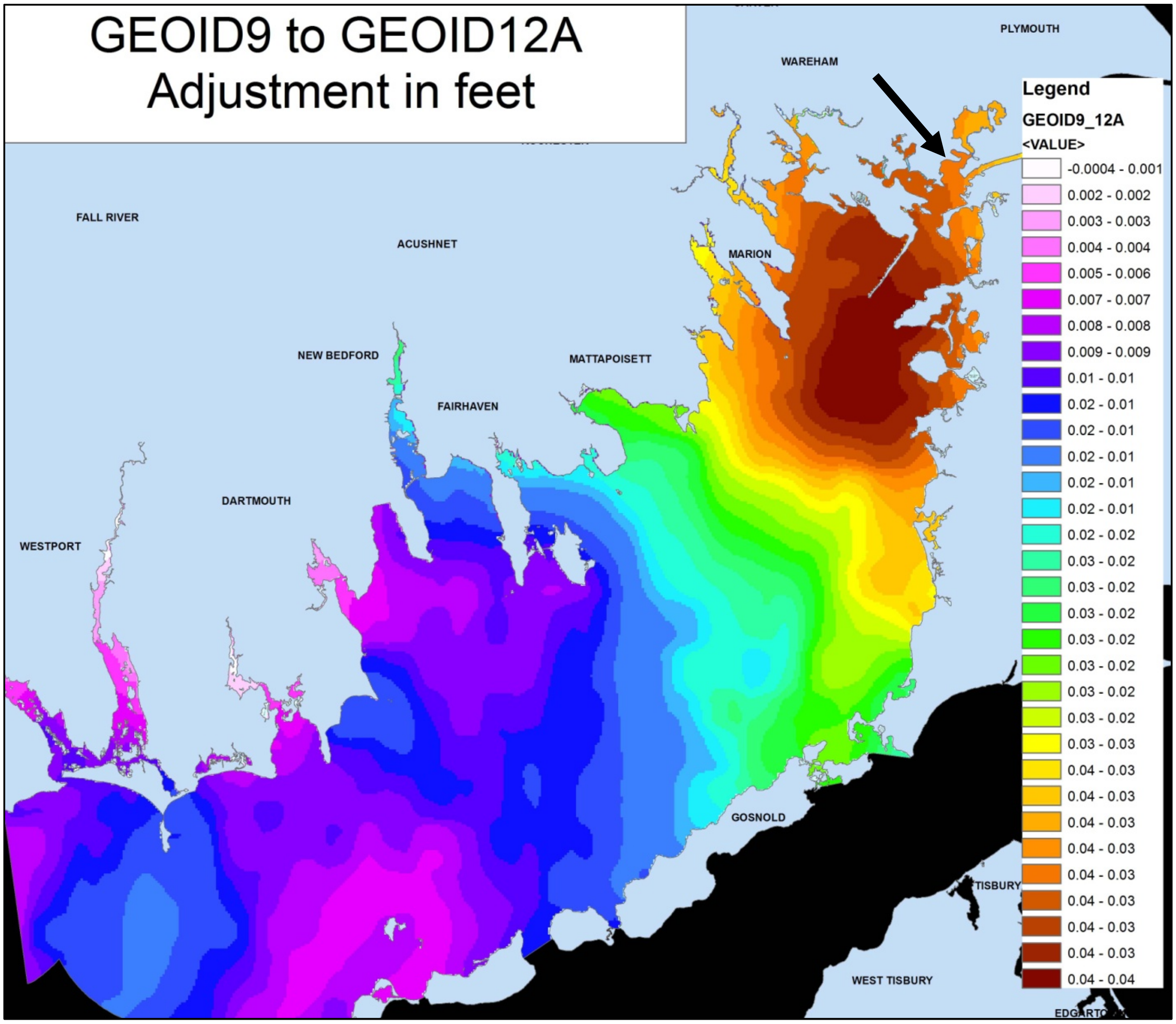

Fig. 4. Fig. 3. Adjustment in converting NAVD88 GEOID9 elevations in feet to NAVD88 GEOID12a elevations as reported in VDatum 3.2 (March 2013). The LiDAR datasets do not use the same GEOID elevations as VDatum. This figure shows the correction factor (in feet) needed for the 2010 Northeast LiDAR. This figure is relevant only for the east side of Buzzards Bay (Bourne, Falmouth, and a portion of Wareham to the arrow). The elevations represented by the color key must be subtracted from VDatum elevations to obtain reported LiDAR elevations. Note that the correction factor is negligible for the 2010 Northeast LiDAR dataset.

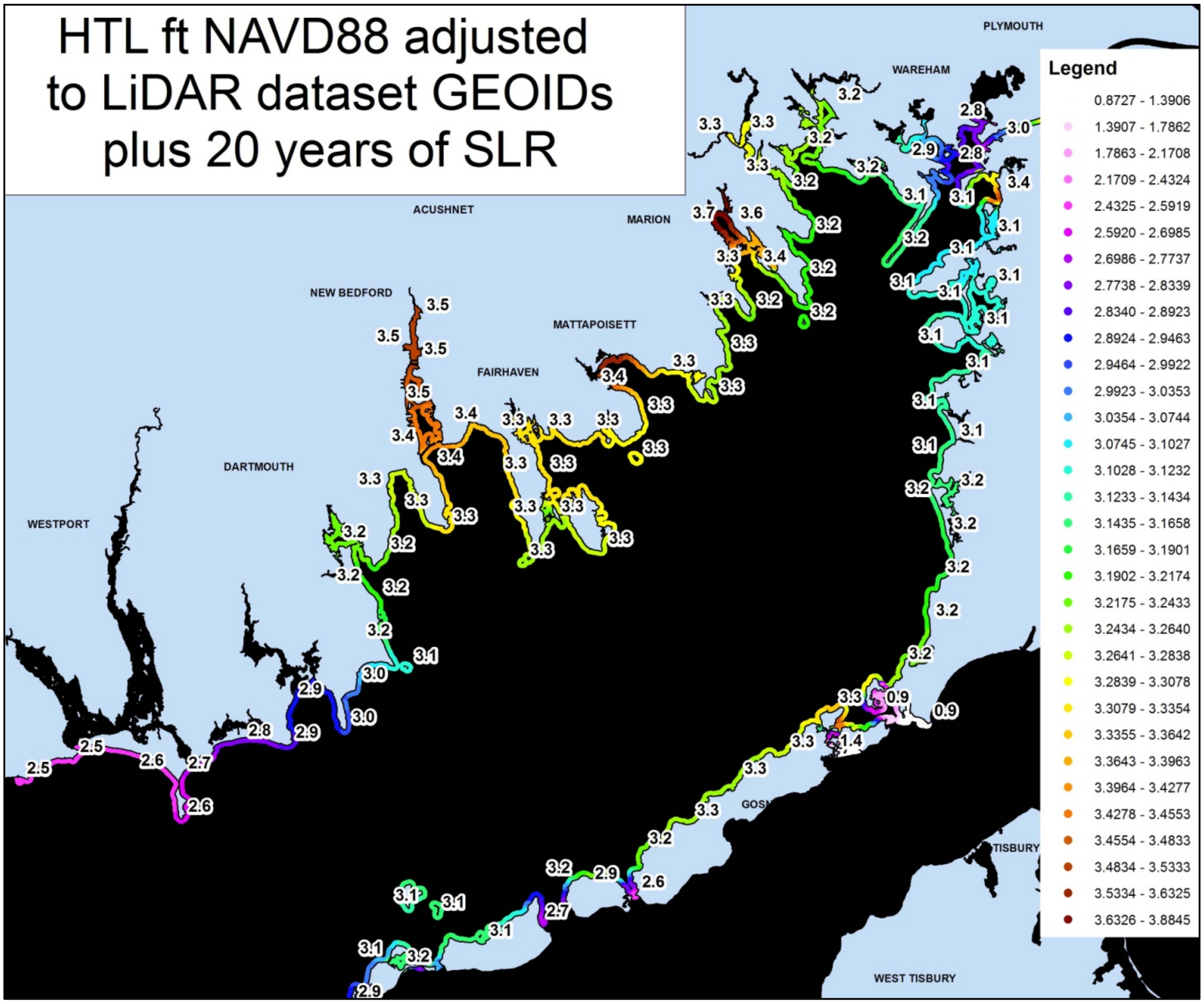

Fig. 5. LiDAR elevations of presumed salt marsh boundaries in non-tidally restricted areas as derived from Eq. 1 (only near coastal points shown and selected values are shown). Note that these values apply to the two LiDAR datasets used (FEMA 2006 LiDAR for western Buzzards Bay and 2010 Northeast LiDAR for eastern Buzzards Bay). This map also accounts for sea level rise that occurred since the midpoint of the last tidal epoch.

A7. Special training certification

Personnel performing the analysis using ArcGIS software by Esri (ArcMap 10.1) under this QAPP will be familiar with and have previous experience using ArcMap ArcView software, and will receive any necessary training by the Project Manager.

A8. Organizational chart

The flow of information and analyses, data, and report review will follow the organization chart in Fig. 6 for the various phases of the project which include (1) internal project analysis, data development, and review; (2) external reviews of draft datasets and draft reports, and (3) submission of draft final materials to EPA for review and approval.

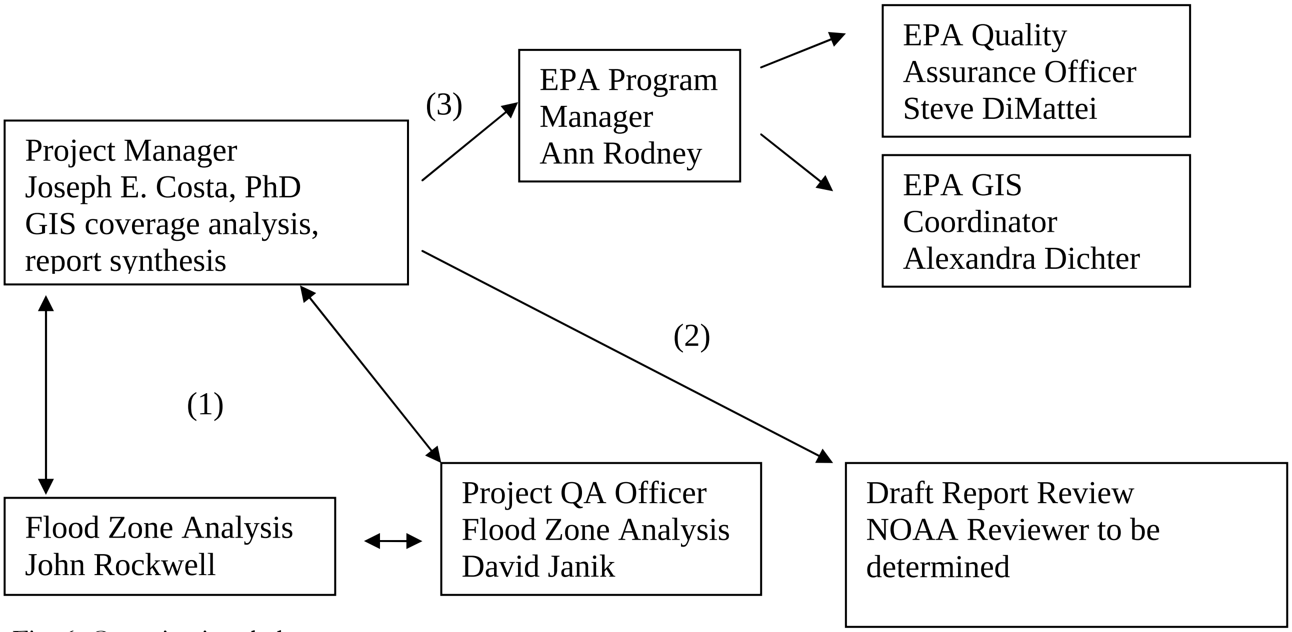

Fig. 6. Organizational chart.

A9. Data quality objectives and criteria
This effort involves a Geographic Information System (GIS) analysis using existing GIS datasets, particularly new LiDAR data that is available as bare earth digital elevation models (DEMs) in the form of triangular irregular network (TINs) or as elevation raster files. The details and quality of the 2007 data is summarized in the 2008 report *Flood Mapping Activities for Plymouth and Bristol Counties, Massachusetts* (CDM Smith, 2008[14]). For Cape Cod, data from the 2012 NE LiDAR project will be used. This data exists as DEM raster IMG files.

The maps resulting from this effort can be used as planning tools to assist municipalities and state resource managers to identify both existing tidally restricted marshes, and those marshes that have the greatest potential to expand inland with sea level rise. The maps can also help target public land acquisitions in sensitive areas.

A10. Documentation and records
It is anticipated that a majority of the internal documentation and record transfer within the project will be completed electronically. Hard copy and electronic copy submittals of deliverables to EPA Region 1 will be submitted to MassGIS for peer review as appropriate, then delivered to EPA. Electronic and hard copy documentation version control, updates, storage, tracking, and distribution will be the responsibility of the Project Manager. Examples of electronic documentation include metadata to accompany GIS data files generated. Because existing software will be used for all phases of this project, it is not necessary to develop any new file types or protocols.

[14] Flood Mapping Activities for Plymouth and Bristol Counties, Massachusetts. Task Order 18 Activity 1--Topographic Data Development / Acquisition Summary Report Contract No. EME-2003-CO-0340. Task Order T018. Prepared for: FEMA Region I.

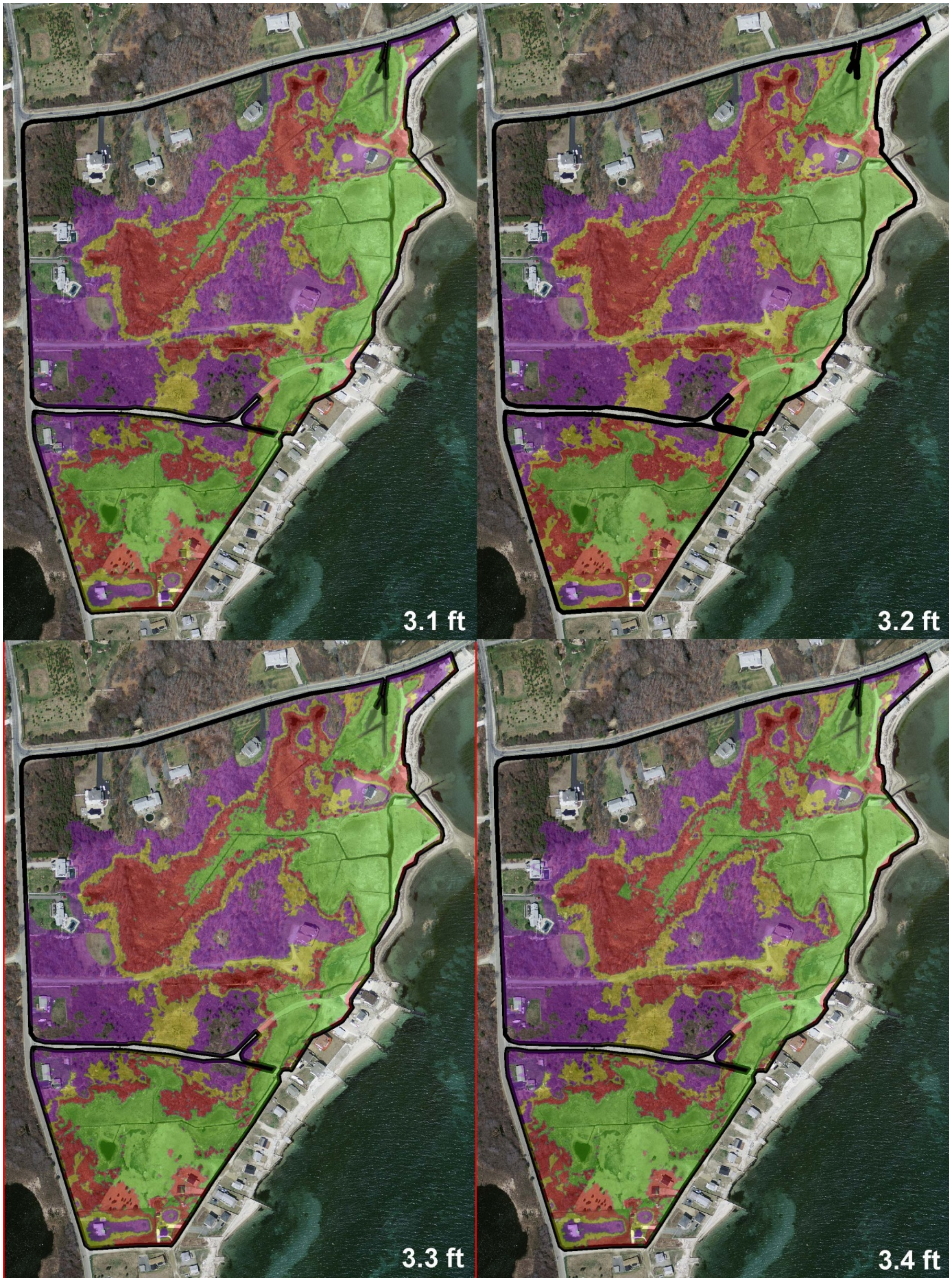

Fig. 6. Expansion of salt marsh assuming a different marsh boundary elevation as a starting point (3.1, 3.2, 3.3, and 3.4 ft respectively). Maps show assumed current conditions (green), and 1-, 2-, and 4- foot sea level rise scenarios (red, yellow, and magenta, respectively). The actual HTL elevation at this site is 3.3 ft.

Section B. DATA ACQUISITION AND FILE MANAGEMENT

This section addresses aspects of project design and implementation to ensure that appropriate methods for the collection of existing datasets are used in this study. This study does not require the generation of new field data.

B1. Collection and processing of existing data

The LiDAR GIS data for this study has already been obtained from USGS (also available through MassGIS) and FEMA. Although the two LiDAR sites were taken at different times, and use different Geoids (which are corrected for as described above) the data sets are of comparable quality and positional accuracy, and where they overlap, show good agreement. Any discrepancies between the two data sets will be discussed in the project reports.

Electronic documentation and data will be stored on individual computers with weekly full backups and daily incremental backups. The backup data will be hosted on USB drives with additional monthly archiving on CDs stored offsite. Upon completion, data will be posted online in final form, including shapefiles with appropriate metadata.

B2. Acquisition methods

Most datasets will be obtained by email from agency contacts or downloaded from publically accessible websites.

B3. Chain of custody

Chain of Custody is not applicable to this study because no new data will be acquired in this study.

B4. Analytical methods

Using the high tide line elevation already calculated by the Buzzards Bay NEP as outlined in section 6.1.1, the analytical approach used in this study will largely focus on converting LiDAR TINs to polygons that represent the existing HTL elevation and each sea level rise scenario change. The workflow for this process for TIN or IMG (imagine) files is summarized in the box below and in Fig. 7. For IMG raster digital elevation models, omit step 2.

ArcView GIS has all the necessary functions to manipulate and intersect the datasets (3D Analyst and Spatial Analyst extensions needed for some steps). The GIS data can also be used in an ArcView environment for simple applications such as calculating the amount of area in the expansion zones. No field collection of data or ground truthing is required for this analysis.

All data files, input and output files, spreadsheet, database, and word processing files will be stored in an appropriate format for the software used. Current and widely used software packages will be used for electronic spreadsheets (Excel) and word processing (MS Word). Intersected datasets will primarily be analyzed in Excel spreadsheets using built in pivot table functionality. If necessary, files for these software packages can be converted back and forth between formats without a loss of data.

B5. Quality control

Various visual inspections and check sum approaches will be used to ensure areas of salt marshes are calculated and reported correctly. Boundaries and vegetation types of representative marshes will be investigated to determine that the selected elevation boundary is appropriate.

Workflow for Converting TINs to SLR Scenario Polygons

Note: For dealing with a large numbers of files, most of the steps can be batch processed independently in Arc Toolbox). Some steps require 3D Analyst or Spatial Analyst extension licenses.

1) Add TIN files to the ArcGIS map.

2) Convert the TIN to a raster file. In Arc Toolbox use the command > 3D Analyst Tools> From TIN> TIN to Raster. In the dialog box for this command, select output resolution by the cell size 0.25 m. Once the raster is created, you can classify the symbology as per the table in step 3, or importing the symbology from a raster file already processed, or just continue to step 3.

3) Reclassify the raster files in step 2 (Spatial Analyst Tools> Reclass> Reclassify or Reclassify by table) using this table below to a reclass raster directory. Change the high marsh value to the LiDAR elevation specific to the site. In this example table, the boundary of the high marsh is presumed to be 2.9 feet.

Class	elevation NAVD88	to elevation NAVD88	comments
1	-100	0	lowest value to zero
2	0	1	convenient for approximate low marsh boundary
3	1	2.9	local upper marsh boundary (to High Tide Bush *Iva*)
4	2.9	3.9	marsh boundary + 1
5	3.9	4.9	marsh boundary + 2
6	4.9	6.9	marsh boundary +43
7	6.9	100	6.9 to highest value

4) Export reclassified raster to polygon coverage (Conversion Tools> From Raster> Raster to Polygon with simplify polygons checked) into recoded_rasters directory. Make sure the file name indicates high tide boundary elevation (e.g. "30" for 3.0 feet, "31" for 3.1 feet, etc.)

5) Repair the geometry of this file (Data Management Tools> Features>Repair Geometry).

6) Aggregate isolated depressions in higher elevation zone into the higher elevation zone. To do this, run Analysis Tools> Proximity> Polygon Neighbors reporting by both ID and GRIDCODE and save to recode_rasters directory. Open the resulting dbf file in Excel to prepare a pivot table using source ID as the row labels and the following value fields: average source grid code, number of neighbors, average neighbor grid code (formatted to 2 decimal places), and sum of number of nodes. These values must exclude node neighbors (filter by node=0; neighbors defined only by a shared point are excluded, neighbors must have a shared edge, sum of nodes should equal zero as a cross check). Export the resulting table as a CSV file for joining by polygon SRC ID. Delete blank header row and the last summation row of the pivot table in the CSV file. Header labels must be ArcGIS format compliant.

7) Export the joined table as a new shapefile. Add additional field call FIN_GRIDCD (final grid code). Assign final grid code the value of the original gridcode, then change it according to these rules:
a) For each polygon ID, if the mean neighbor grid code is exactly 1 unit higher or greater, the original grid code is increased by one, otherwise the original grid code remains the same. This rule results in depressions that are completely surrounded by higher areas being assigned the same code as the surrounding high areas.
Elevation will be ignored. The results of steps 6 and 7 are shown in Fig. 7.

Note on assigning generated spline interpolation HTL raster model: Extract raster elevations to point coverage as follows: Spatial Analyst>Extract values to Points> (select point & raster coverages)> (join exported file to points)

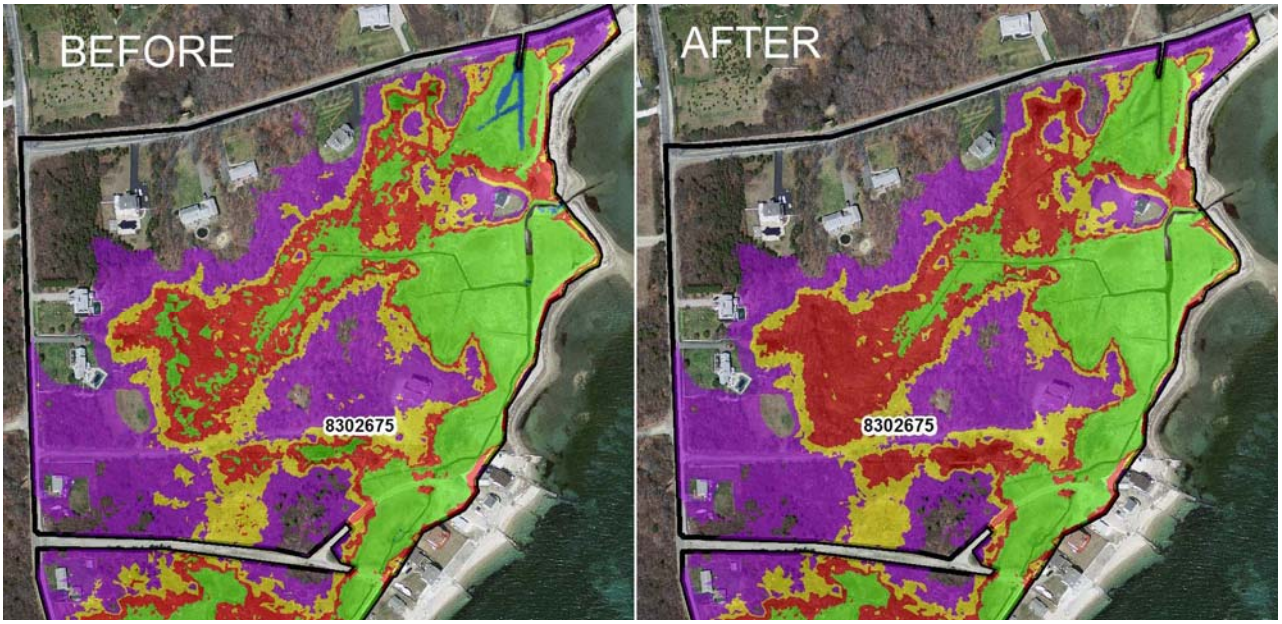

Fig. 7. Processing of digital elevation model results to assign isolated depressions (in Fig. left) to higher elevation classes (resulting final classification of elevation scenarios on right).

B6-B9. Standard QA plan data acquisition elements
These standard QA plan elements are not applicable because no new data will be acquired in this study. The project involves only a synthesis and analysis of existing data using the protocols described.

B10. Data Management
The Buzzards Bay NEP is the governmental authority for storage, access, and disposal of all records. Relevant records and data pertaining to the project will be sent to EPA in the final report. In addition, all hard copy project files will be stored in the EPA OCCWQ office for at least five years after the project's termination, and then moved to the OCC warehouse indefinitely. All electronic files will be maintained on the EPA OCC electronic server indefinitely. Digital data will be posted on the Buzzards Bay NEP website www.climate.buzzardsbay.org. All GIS data files will be fully documented in corresponding Metadata files.

Section C. ASSESSMENT AND OVERSIGHT

This section addresses the activities for assessing the effectiveness of the implementation of the project and associated QA and QC activities, particularly the development of the estimated approximate salt marsh boundaries for non-tidally restricted areas, and their expansion with the three sea level rise scenarios. This section also applies to the review of draft materials by outside reviewers.

C1. Data review, validation, and verification requirements
After the elevations of the upper salt marsh boundary are estimated from the predicted high tide line elevation. Selected sites will be confirmed by visual inspection of orthophotographs and with field photographic documentation of vegetation types. This information will be used to discuss the general reliability of the approach in the study reports.

All resulting maps will be reviewed by the Project Manager and GIS QAQC officer for consistency among the data sets and to ensure correct elevations were selected in the LiDAR datasets. These final coverages will also be sent to a NOAA and EPA staffer for review. As part of the data review and validation, inadequacies of the dataset or inconsistencies will be discussed with the Project Manager. Any problem areas shall be documented and revised if necessary.

Section D. DATA VALIDATION AND USABILITY

This section describes QA activities that occur after the data collection or generation phase of the project is completed, specifically related to the draft and final reports and maps to be prepared for coastal resource managers. Implementation of these elements ensures that the data conform to the specified digital quality objectives (DQOs) criteria, thus achieving the project objectives.

D1. Validation and verification methods
Because this project involves an extrapolation of a natural resource boundary based on assumed elevations that vary around Buzzards Bay, there are uncertainties in NOAA's tidal models, and because the LiDAR dataset being used has its own uncertainties, the proper caveats will be distributed with the datasets and findings. However, we will conduct some real world validation or verification of the boundaries of salt marshes in non-tidally restricted areas to ensure that the elevation of the high tide line is generally appropriate marsh boundary for the analysis. We leave open-ended how quickly the 1, 2, and 4-ft elevation increases may occur, so the maps produce will predict salt marsh elevations with the specific increases in sea level.

D2. Reconciliation with user requirements
Results will be reviewed internally and externally, as described, to assess usability in the context of their specific intended use (identified in project specific QAPP appendices). Project leaders will meet with outside agency representatives (at least once) to reconcile any differences between data quality and data requirements. Specifically, once the final maps are determined to meet the DQOs of the project, the maps and draft report of findings will be posted on the Buzzards Bay NEP website for use by natural resource managers at all levels of government.

Comments received will be included in the final reports and maps. In general, the maps produced will be deemed usable if acceptance criteria are met and the Project Manager determines that municipal comments were suitably addressed. However, if performance criteria do not meet the project's requirements for DQO's as outlined in this QAPP, the shapefiles may be revised. A QAQC report on all of the above items will be included as an Appendix to the Final Report to each municipality.

If Data Quality Objectives are not met, corrective actions will include discussion with MassGIS regarding rejecting or revising datasets, and updates of related reports and maps.

Bibliography

Bertness, M.D. 1992. The ecology of a New England salt marsh. American Scientist, Vol.80:268.

Bertness, M.D., Ewanchuk, P.J., and Silliman, B. R. 2002. Anthropogenic modification of New England salt marsh landscapes. PNAS 99:1395-1398.

Bertness, M.D., Silliman, B.R., and Holdredge, C. 2009. Shoreline development and the future of New England salt marsh landscapes. In: Silliman, B., Grosholz, E.D., and Bertness, M.D., eds. Human Impacts on Salt Marshes: a global perspective. University of California Press, pp. 137-148.

Fitzgerald D.M., Fenster, M.S., Argow, B.A., and Buynevich, I.V. 2008. Coastal impacts due to sea level rise. Annu. Rev. Earth Planet. Sci. 36:601-647.

Hladik, C.M., Alber, M., 2012. Accuracy assessment and correction of a LiDAR-derived salt marsh digital elevation model. Remote Sensing of Environment 121:224–235.

IPCC. 2007. Climate Change 2007 - Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, New York, NY.

Myers, E.P. 2005. Review of Progress on VDatum, a Vertical Datum Transformation Tool. NOAA/NOS Coast Survey Dev. Laboratory NOAA/NOS Coast Survey Dev. Lab., Silver Spring, MD

National Oceanic and Atmospheric Administration Coastal Services Center (NOAA CSC). 2011. New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts. Proceedings of the 2011 Solutions to Coastal Disasters Conference, American Society of Civil Engineers (ASCE).

Nixon, S. W., 1982. The ecology of New England high salt marshes: a community profile. Biological report 81, no. 55, Washington D. C., Fish and Wildlife Service.

Nydick, K., Bidwell, A., Thomas, E., and Varekamp, J.C. 1995. A sea-level rise curve for Guilford, Connecticut, USA. Marine Geology 124:137-159.

Orson, R. A., Warren, R. S., and Niering, W.A., 1998. Interpreting sea level rise and rates of vertical accretion in a southern New England tidal salt marsh. Estuarine, Coastal and Shelf Science 47:419-429.

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

Schmid, K.A.; Hadley, B.C., Wijekoon, N., 2011. Vertical accuracy and use of topographic LiDAR data in coastal marshes. Journal of Coastal Research 27(6A):116–132.

Warren, R.S., and Niering, W.A. 1993. Vegetation change on a Northeast tidal marsh - interaction of sea-level rise and marsh accretion. Ecology 74:96-103.