Project Report: Mapping and Restoration Inventory of Fringing Marsh Habitat in the Casco Bay Estuary

Funded through grants from the Casco Bay Estuary Partnership and the U.S. Environmental Protection Agency

3.2008

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Environmental Protection Agency Region 1

Acknowledgments

All participants in this project would like to extend our sincere appreciation to the DeLorme Publishing Company, Inc. for their generous offer of the use of their GIS software and Topobird Imagery in completion of the goals of this project. Without their kind assistance, this project would have been far more difficult, if not impossible.

We (the field survey team especially) would also like to thank the many land owners and other residents of towns surrounding Casco Bay who were so supportive in allowing a sometimes rather disheveled appearing crowd to wander their properties, helping us find the exact location we needed when we were lost (or the maps were not *quite* right), and otherwise assisting in so many ways with our efforts to map the fringing marshes of Casco Bay.

Thank you all!

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Executive Summary

During the spring and summer of 2007 a survey of the fringing marshes existing along the mainland coast of Casco Bay was commissioned by the Casco Bay Estuary Partnership and the U.S. Environmental Protection Agency. The work was performed by personnel supervised by the Wells National Estuarine Research Reserve (WNERR) in Wells, Maine.

A delineation of fringing marshes based on aerial photography was performed during the spring and early summer months. This delineation, based upon aerial imagery taken in 2003, identified approximately 1,160 marsh units along the mainland coast of Casco Bay (islands were omitted from this study). Later in the summer, after maturation of marsh vegetation, survey teams were dispatched in two separate efforts in support of the image-based identification. Boat transects were taken along representative shorelines and fringing marshes detected were marked at each end with a GPS point allowing an approximation of marsh location, and extent, to be recorded. Survey teams on foot visited a number of randomly-selected sample points and performed on-site measurement of marsh area (total, high marsh, low marsh, and major invasive patches), an estimate (based on elevation differences) of potential total marsh area after a forty centimeter (40 cm) rise in average sea level, and performed a 'rapid assessment' of marsh characteristics and degradation condition.

Based on the estimated average fringing marsh area, there is approximately 41 hectares of marsh covering nearly 150 km of the mainland coastline of Casco Bay. While some marsh is very healthy, development and other factors have taken their toll. The average impact assessment score was 73% (100% would be a 'perfect' score, with no problems); the median was just slightly higher at 75%. The average degradation score was 0.17 (with unity, '1', being the worst possible

score and '0' the best); similarly, the median was slightly better at 0.15.

The image-based identification performed well in identifying marshes. Based on 2007 'surface truth' provided by the boat transects, the image delineation (from 2003 imagery) identified between 50% and 70% (depending on the radius of tolerance used to define detection of a single marsh) of the marshes. When changes to the marshes over time are considered, this reflects favorably on its use. The marshes identified can serve as a basis for further efforts to find, assess, improve, and protect marshes in Casco Bay.

Introduction

During the spring and summer of 2007, the Casco Bay Estuary Partnership (CBEP) and the U.S. Environmental Protection Agency Region 1 sponsored a project through the Wells National Estuarine Research Reserve (WNERR) to map and assess impacts to fringing marsh habitat in Casco Bay, Maine. The shoreline of interest was the mainland coastline between the southern/western point of Cape Elizabeth and the eastern/northern Small Point. Islands (those at a significant distance from the mainland or not connected via bridge or causeway) were beyond the scope of this project.

The project began with the delineation of fringing marshes identified through the use of aerial imagery displayed in GIS (Geographical Information System) software. This identification was performed during the spring and early summer of 2007. Later in the summer, when marsh vegetation had reached a more mature growth stage, field surveys were performed at selected sites to collect surface measurements (for comparison to those found by image-delineation) and information not available from aerial imagery. The goals of the project were to develop an inventory of fringing marsh in the study area, to assess the abilities of aerial-imagery-based identification of fringing marsh in typical Maine coastal environments, and to obtain restoration and surrounding land use information for a subset of the marshes identified.

Data, Methods, and Products

Study Area

The study area comprised the mainland coast between Cape Elizabeth in the southwest and Small Point in the northeast. Islands, in general, were not included in the study coastline, although some islands lying close to or connected to the mainland were evaluated and, where fringing marsh was found, it was delineated. The study area was divided into two regions: the western region, comprised of approximately 250 km of coastline between Cape Elizabeth and Harpswell; and the eastern region, comprised of approximately 400 km of coastline between Harpswell and Small Point (***Figure 1).***

The coastline shown was evaluated visually using the DeLorme XMap GIS software and the accompanying Topobird imagery. Areas interpreted to be fringing marshes were delineated by drawing a polygon enclosing the identified marsh. Field surveys were later conducted at randomly selected points within the two regions of the study area. See the '***Methods***' section for more details.

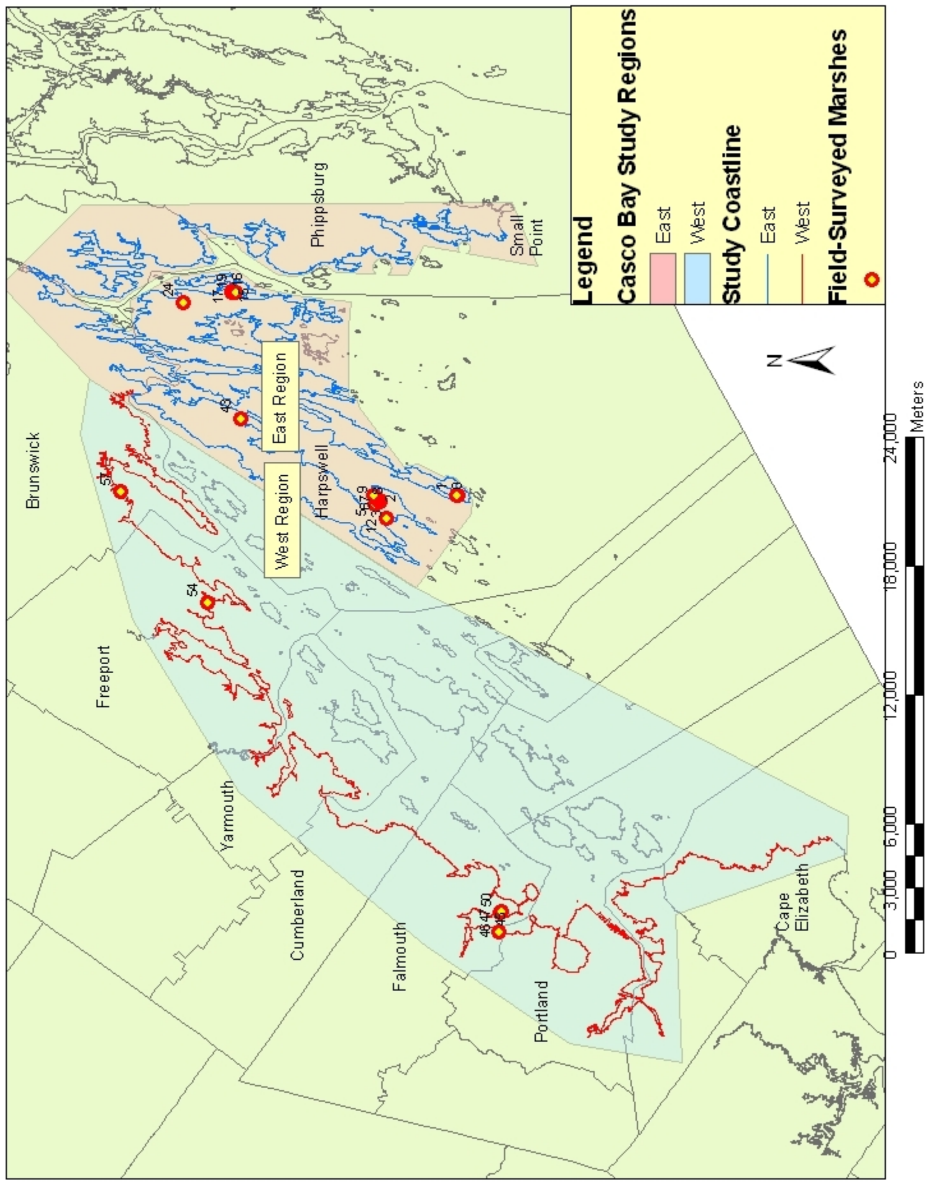

Figure 1: Study area for fringing marsh project, showing the two regions, the two coastlines of study, and the location of randomly-selected (within each region) field survey sites.

Data

Image Data

Digital Imagery Selection Considerations

Data for the GIS delineation of fringing marshes in Casco Bay was primarily image data – often referred to as raster data in GIS use. A number of sometimes-competing criteria led to the selection of the data used, and some of those criteria are briefly described below.

Pixel Considerations. In digital remote-sensing imagery (including both imagery originally captured on film, then digitized, and imagery initially captured in digital format), resolution on the ground and color content is determined by the number and memory 'size' of the 'picture elements' – or pixels – in the image. A digital image is comprised of rows and columns of pixels, each pixel representing a certain, approximately square, area of the imaged scene and each pixel represented in computer memory by one or more words. The number of pixels (the number of columns across times the number of rows from top to bottom), along with the real area (on the ground) imaged, determine the resolution. The number and size of words assigned to each pixel determine the accuracy and 'depth' of color that can be represented in the image. Memory requirements (and associated processing requirements) increase with the number of pixels, the number of words per pixel, and the size of each word.

Season and time. Another consideration especially important for this type of work was the season in which the imagery was taken. Marshes may be growing in May, but there is little biomass (and certainly not a lot visible from an airplane) until later in the summer – late June or July. Unfortunately, many aerial imagery projects attempt to limit the visual obstruction that occurs from trees and other foliage by intentionally flying after the snow cover has melted but prior to the emergence of leaves – 'leaf-out'. This means that much of the imagery produced for other purposes (for example, municipality planning, facility planning, and other common uses of such imagery) is not well suited to delineating fringing marsh (or other salt marsh, for that matter). This is particularly important in determining marsh from other vegetation types as the height and texture differences become more pronounced as the vegetation grows (particularly where marsh abuts mowed lawn in developed areas). At times, imagery taken prior to leaf-out was useful as a second source to verify the boundaries of marsh peat (especially, for example, where a visible salt marsh disappeared beneath deciduous tree cover along a coast), but much of the standard imagery could not be used for primary marsh identification as the differences between senescent marsh and other types of vegetation is often very difficult to detect.

Imagery is usually a trade-off between resolution (many pixels in the same real ground area mean better resolution but larger data files), color (more words per pixel and larger words per pixel mean more accurate color, or other bands, such as the near infrared, NIR, but larger data files), the number of flights (more flights with less ground area covered per image taken leads to better resolution with greater expense both during and after the image capture), and other potential factors. For our purposes, color imagery was required with a minimum of six or twelve inch ground resolution. Resolution less than one foot (i.e., where each pixel represents a ground are of greater than 1 ft^2) made identification of the marsh area difficult. Even at that resolution, individual stalks were 'invisible' (a stalk of cordgrass is only a fraction of an inch wide and even a leaf is less than an inch across), but the overall color and texture were visible, and outlines could be determined between vegetation types (see the 'seasons' description below). The scope of this project did not include collection of new imagery, so only existing imagery was considered.

Even during the proper season – with reasonably mature growth – the height of the tide was a significant factor in the ability to identify and delineate marshes. The ideal time was low tide, when the marsh would be most exposed, its lowest edge visible above the low waterline. Although dead-low-tide was not necessary, high tide imagery could conceal some low marsh areas beneath the water.

Georeferencing and Image Processing. A final consideration for the imagery used in our identification was the processing performed after the raw imagery was captured during a flight. The goal of our image-based work was to identify the approximate location and extent of fringing marshes along the coast of Casco Bay. Although obtaining precise location (down to an error level of inches, for example) from the aerial photography was never intended, reasonably accurate location (within feet of the true location) of the identified marshes with respect to other GIS-based features *was* expected. This meant that the imagery used for identification had to be processed and referenced properly after capture.

Orthorectification. The first consideration in this regard was orthorectification. As anyone who has taken pictures of trees or tall buildings from the ground knows, there are perspective problems that appear due to the curvature of the camera's equidistant surfaces (and the projection of these surfaces onto a flat film or electronic display), the opposing curvature of the earth, and the variation of height in objects on the earth's surface. The most significant effect of this in terms of our marshes was that, if one half inch at the center of the photo represented ten feet of real ground distance, the same half inch nearer the edge of the photo would represent a dramatically different ground distance. This kind of distortion in distance is sometimes visually interesting but needs to be removed by orthorectification of the image when distances (and

Figure 2: Citipix (or Ortho_HF) imagery of Falmouth coastline.

Figure 3: Maine Department of Marine Resources eelgrass imagery of Falmouth coastline.

perspectives) are important. We needed orthorectified imagery.

Georeferencing. Second, again because we hoped to actually provide a reasonably accurate location of the identified marshes on a map, the location of each marsh on the earth's surface was needed to a reasonable accuracy. This is georeferencing – where the location of points in the image, when projected in a GIS system, are referenced correctly to geographical coordinates such as latitude and longitude. Although we could perform rudimentary georeferencing ourselves, if necessary, imagery that was professionally corrected (a more involved process) would deliver better results with less distortion, improving our end product.

'Public' Sources of Data

The state was the primary provider of appropriate imagery candidates. The state GIS web site (http://apollo.ogis.state.me.us/) provided access to a number of image sets covering a majority of the coast. The imagery was available, in most locations, with six-inch resolution (referred to as Citipix or Ortho_HF imagery), although only twelve-inch resolution imagery (Ortho_1F) was available for some locations in the study area (primarily the eastern portion, near Phippsburg). This imagery (the Citipix or Ortho_HF and the Ortho_1F, respectively) were full-color, orthorectified, georeferenced images of Maine land and coastline.

However, the state's imagery was intended to provide information useful to planners, engineers, and others desiring to see, especially, the built-up infrastructure (roads, railways, paths, buildings, and so forth) of an area. To this end, the available pictures were taken in early spring, before 'leaf-out', when most plants develop summer foliage. While some marsh features were visible in this imagery, its use for this project was limited to a 'backup' capacity: it might be used to help determine whether or not a questionable area (in another photo) was or was not fringing marsh, but could not be used for primary identification.

Maine Department of Marine Resources Eelgrass Photos

The Maine Department of Marine Resources (DMR) possessed another set of imagery that was of use. These aerial photos had good resolution, were taken during the summer (with the intended use of identifying eelgrass beds in coastal waters, so vegetation was present), and some were orthorectified and georeferenced. Unfortunately, they were never intended to provide coastal coverage, so that there were missing sections of the coastline, and not all images were georeferenced. They might do for much of the coast, but would leave 'holes' in which there was no coverage and the georeferencing could easily be less than ideal. They were, however, obtained and used as another 'backup' to the primary imagery, to check a questionable location and for an alternative, possibly better, view, as well as to ensure that eelgrass beds were not mistaken for fringing marsh.

DeLorme TopoBird Imagery

Through a series of inquiries and a subsequent chain of contacts, a set of imagery was found at The DeLorme Publishing Company of Yarmouth, Maine, that had the characteristics desired. The resolution was approximately twelve inches and the clarity was excellent, owing partly to the equipment used to obtain the images. The flights had all been made during the summer season – in July – so that there was a full cover of marsh vegetation. DeLorme graciously loaned us the imagery and copies of XMap (the mapping software they produce and in whose format the imagery was saved) for use on the project. This served as our primary image source for identification of fringing marshes. Images of a common location in Falmouth taken from all three sources allow comparison **(Figures 2, 3,** and **4).**

Figure 4: DeLorme Topobird Imagery of Falmouth coastline.

Other Data

The state's GIS website served as the source of a number of non-image data sets (vector data in GIS lexicon) used during our identification. We used the Coastal Bluff Hazards (metadata available at http://megisims.state.me.us/metadata/coastal_bluff_hazards.htm) layer, or theme, from the Maine Department of Conservation and the Maine Geological Survey as a guide to the coastline of Casco Bay, following most of the same contours when searching for and delineating marshes. This layer also provided a field containing an estimate of the classification of the type of shoreline throughout most of the study area – one classification being salt marsh (or other vegetated shore). We utilized this as a guide and found that our identification didn't always agree (due to differences in years, interpretation means, and classifications, among others), but the areas identified in this layer as marshes were paid particular attention in the imagery in an effort to ensure that all potential fringing marshes were inspected and, where appropriate, identified.

Other data layers were used in support of our efforts, although they were not directly involved in the identification process – these included road layers and municipality boundaries (**Figure 1**). Again, these were almost exclusively obtained from the Maine Office of GIS website.

Methods

Image-Based Delineation

The image-based identification primarily involved following the coastline in the imagery (the DeLorme Topobird imagery being the primary source used for this purpose) at a scale that was appropriate for picking out sections that might be fringing marsh. Fringing marsh was primarily identified by its color, texture, and location. Once a marsh was identified, a polygon (a shape created by hand in the XMap – or ArcMap – program whose boundaries approximately followed the marsh boundaries and which could be displayed in the GIS program) was drawn around it and was saved to a database of identified marshes that would eventually become part of the shapefile output (compatible with most GIS systems) deliverable as part of this project.

Initially, the database included only the polygon itself (data that identified the marsh area outlined with the drawing tool) and the polygon ID (a GIS-program-assigned identification number). As work progressed, several modifications were made to the original database in an attempt to better capture parameters of the marshes and process. The added fields included:

1. **Marsh_Type**: a field/variable assigned either 'M' (mixed marsh – an undetermined mix of high, low, and, potentially, invasives), 'H' (high marsh, to the best of our identification ability), 'L' (low marsh, to the best of our identification ability), or 'I' (suspected invasive species);
2. **Confidence**: a field/variable assigned an integer between '1' (very high confidence) and '4' (very low confidence) attempting to describe the surety of the identifier in the correct identification of the particular marsh in question as a fringing marsh (as opposed to other vegetative or non-vegetative features);
3. **Cst_Type**: A single character descriptor of shoreline type assigned either a 'F' (forest with overhanging or concealing foliage), 'M' (mud, rock, or unconsolidated bottom, usually partially or wholly covered with algae), or 'U' (for developed) as an indicator of the most prevalent factor challenging identification of the marsh in question.

The variables were somewhat indicative of progress on the learning curve of marsh identification. Initial confidence in the ability to identify marshes (even to the extent of separating high marsh, low marsh, and, sometimes, patches of invasive species) soon gave way to the realization that this was – in most cases – overly optimistic. While some delineation of that detail was possible, the image signatures necessary for that type of separation were rare. More often, there was doubt about the identification. This led to the addition of the confidence estimate as a somewhat-subjective means of quantifying the operator's confidence in the identification.

Not all records were assigned values for all three of the above variables, particularly the

'Cst_Type' variable. The variables were added at different times during the identification effort and were, primarily, used as aides for the photo-interpretation. Because of time constraints, we did not fill in these fields for marshes identified prior to the development of these variables.

The 'Cst_Type' variable was added as concerns about accuracy led to an expanded field truth component to the the project using vessel-based shoreline surveys. With experience, identification became a process of following the coastline in the primary image source (the DeLorme Topobird imagery) until an area that *might* be a fringing marsh was found. Much of the time, there was limited confidence as to whether the habitat in question truly was a fringing marsh or whether it was (among other possibilities) terrestrial grass beneath overhanging trees, a near-shore eelgrass bed, algae-covered rocks or silt, or some other substrate. Verifying (to the best level possible) that the suspected marsh was (or was not) a marsh involved loading the appropriate imagery from the eelgrass and Citipix/Ortho_HF/Ortho_1F datasets[1] to seek additional discerning features to improve the confidence in the delineation. Often questions remained and an identification was the result of a 'best guess'. Sometimes clarifying details were visible in an alternate image source (for example, concealing foliage not present and marsh peat obvious in an image taken before leaf-out), and an identification achieved an increased confidence level.

One example a common challenge in this process is that of shade cover (**Figure 5**) that prevented identification of the coastal habitat. Use of all resources was made to obtain the results shown which represent the best estimate of fringing marsh coverage.

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1 It was not possible to keep more than a relatively small proportion of the area imagery loaded and displayed at any one time due to the large memory requirements, so images were identified, loaded, and unloaded as necessary.

The end result of the image identification of marshes in Casco Bay was a combined total (marshes from both the east and west regions of the study area) of 1159 marsh candidates, ranging in size from single square meters to over a hectare (10,000 m^2). Determination of the area of image-identified marshes was not one of the initial project goals – only the linear extent was to be determined from the imagery. However, the boundaries of marshes identified using the aerial imagery were delineated as accurately as possible with the GIS polygons, and an estimate of the area of those marshes was possible from these polygon areas.

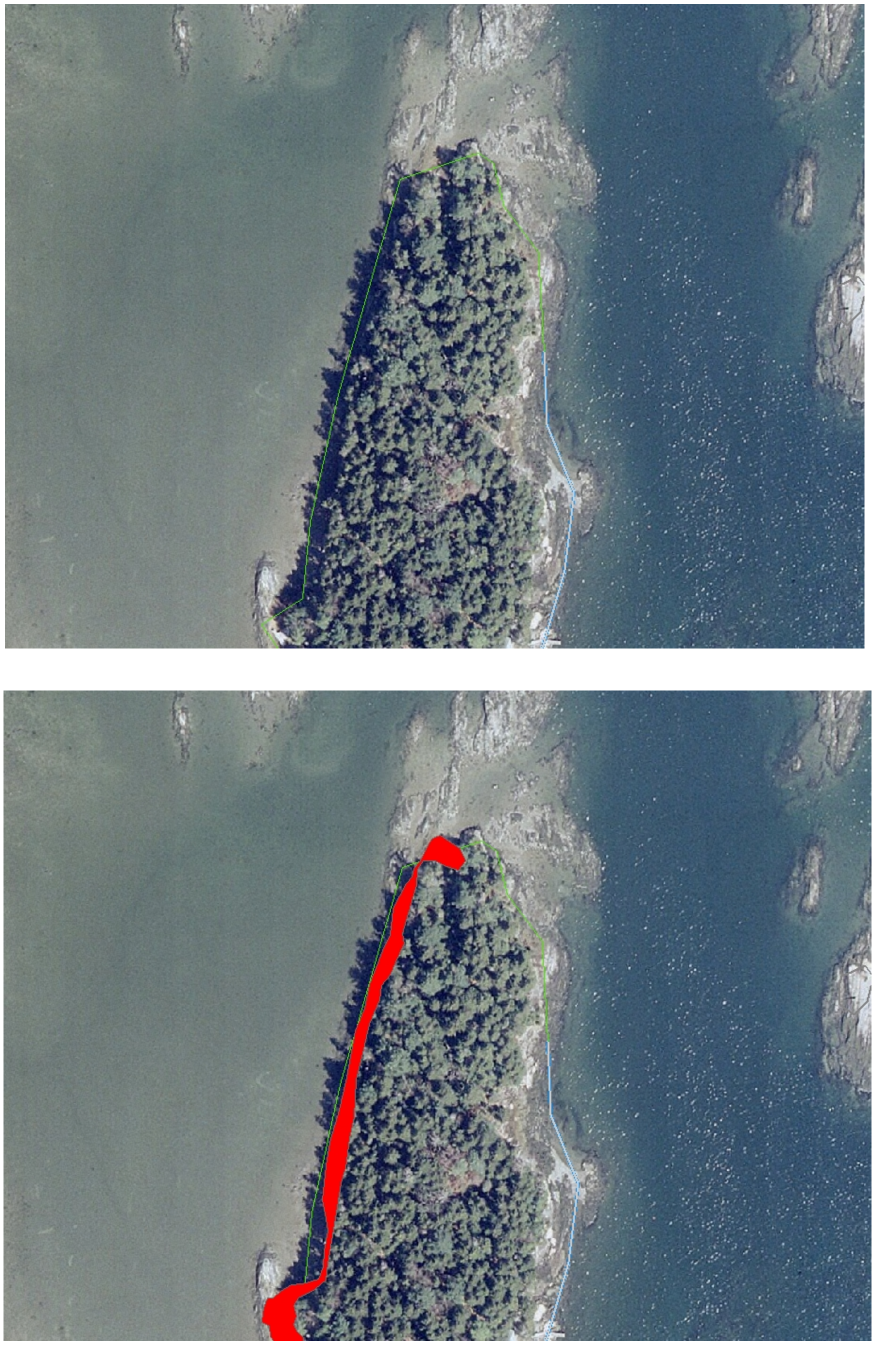

Figure 5: (top) An example of commonly-encountered difficulties - an identification area in which shading by foliage obscured coastal habitat; (bottom) the marsh coverage shown was eventually identified using multiple resources.

Boat-Based Surveys

As mentioned briefly previously, during the image-based identification process, discussions turned towards potential means of estimating the accuracy of the image-based identification process. While there was no means of verifying the marshes present at the time the images were taken (approximately July of 2003), some approximation of the marshes existing then might be obtained by determining the marshes now in existence (summer of 2007). Obviously, marshes grow, shrink, appear, disappear, and move over a four-year period, but a determination of the marshes existing today would be the best possible estimate of those existing when the imagery was obtained and would provide the best available means of estimating accuracy possible.

A boat-based survey of portions of the coast was carried out to obtain estimates of the existing marshes. The boat survey involved a boat traveling slowly parallel to the shore while observers used binoculars to search for marsh habitat. When a marsh was sited, a hand-held GPS (Global Positioning System) was used to mark the length of the marsh and information (including the GPS unit, the waypoint number on the GPS unit, and other relevant data) was entered on a data sheet (a sample copy is shown in the appendix). If necessary, intermediary points were used to mark turns, breaks, and other features of the marsh and recorded on the data sheet. Where some condition warranted concern or interest, a digital photograph was taken and logged on the data sheet.

Initial trials with timing and techniques indicated that approximately high tide was the optimum water level for this effort. A four-hour window centered at high tide was targeted for the boat work. While high water may have concealed some marshes, the high water allowed near-shore access by the boat, increasing the opportunity of finding any marsh, even when mostly submerged. The transects chosen for this boat work were run in an assortment of the environments in which the image-based identification was difficult – representing a mixture of the 'F', 'M', and 'U' categories of the image-based identification.

GPS data points were converted to lines in ArcMap. These lines, in turn, were used to form ellipses (using several radius values) by surrounding the line with a buffer of a specified width. The ellipses were then geographically overlain on the marshes delineated from the imagery to determine where the boat ellipses and the image-identified marshes overlapped. The percentage of boat-surveyed marshes corresponding or overlapping with image-based marshes provided an estimate of the proportion of marshes correctly identified through photo-interpretation (remembering that the four years time gap between data collection for the two efforts would lead to some unmeasurable change in marsh area and location; see **Figure 6**).

Figure 6: Boat transect lines from Xmap indicating linear direction and location of fringing marsh (top) and lines surrounded by 20 m radius buffer (bottom); please see page 29 for further explanation of the processing performed.

Field Surveys

We conducted a field survey of randomly selected marshes along the coast of Casco Bay to 1) further ground-truth the photo-interpreted marshes; 2) assess human impacts and opportunities for salt marsh restoration; and 3) project changes in marsh area and location based on a 40 cm increase in sea level over the next century (IPCC, 2007; Slovinsky, 2006). For this purpose, the Coastal Bluff Hazards GIS theme was modified slightly (to remove some features not desired for this purpose and to limit the theme to Casco Bay) and equally-spaced points were created along the resulting linear coastal outline. A subset of these points was selected within 150 meters of one of the marshes identified during the photo-interpretation; this helped to eliminate points devoid of salt marsh habitat. This subset of points was randomly subsampled separately for the eastern and western study areas to provide a representative sample of fringing marshes to survey. The selected points were surveyed after mid-July when vegetation had reached peak biomass.

At each sampling point a number of marshes was surveyed. If there were multiple marsh units at each sampling point, five marshes on each side of the sampling point were surveyed. If there were fewer than five marshes (or fewer than five accessible), only those marshes present were surveyed. If the marsh present consisted of long stretches of marsh not divisible into discrete units, approximately 300 meters of marsh to each side of the sample point was surveyed; terminating points were estimated based on natural breaks (a dock, a downed tree, a panne, or other notable feature that would allow individuals in the team to generally agree on boundaries). In all, 16 sample points were actually surveyed, resulting in 69 marshes, including two marshes each from Little John and Cousins Islands in Yarmouth.

A standard sampling procedure was performed at each marsh. This included measurement of the marsh using GPS units and completing data forms for each marsh. One marsh at each sample point was treated slightly differently. In an effort to estimate marsh response to rising sea levels, a measurement was made of the estimated marsh area with a forty centimeter (40 cm) rise in sea level.

Common GPS measurements included marking with GPS waypoints the perimeter of each marsh, the high-low marsh boundary, any significant patch of invasives (primarily *Phragmites australis*), and (for the one marsh at each sample point) the perimeter + 40 cm of elevation. The water-marsh boundary of the perimeter was estimated based on the presence of *Spartina alterniflora* in the substrate (usually silt). The high-low marsh boundary was determined based on a visual estimation of dominance of low marsh species (primarily *S. alterniflora*) and high marsh species (primarily *S. patens*, but also including other high marsh plants such as *Distichlis spicata*, *Scirpus americanus*, *S. robustus*, and *P. australis*). The upper boundary of the marsh was approximated by visual estimation of plant dominance, where high marsh vegetation was dominated by upland vegetation. Large patches of invasives were measured separately and receive their own measure. The perimeter of each marsh was first marked by walking the boundaries (as described above) while recording GPS points along the route. The high-low marsh boundary was then similarly marked. During processing, the total marsh area was encompassed by the perimeter points; the high marsh area was then determined by dividing the total area at the GPS line, marking the high-low marsh boundary (**Figure 7**).

Figure 7: Marsh delineation during field survey. This figure shows two marshes with high and low marsh('Perimeter' includes both low and high marsh) indicated in both; the top marsh also shows the +40 cm measurement, the upper edge of which is coincident (to the GPS accuracy) with the existing marsh due to a steep slope; no invasives are present.

At the one marsh per sample point for which response to sea-level rise was to be estimated, the process was slightly different. A laser transit was placed such that it was visible from all points in the marsh to be measured (sometimes a challenge!). As the perimeter was walked, an elevation measurement and GPS waypoint measurement were made. A second GPS waypoint measurement was made at the point uphill from each perimeter point at which the elevation was 40 cm higher. These perimeter + 40 cm points would thus form a second perimeter with an elevation of forty centimeters higher than the actual marsh, and would indicate the potential marsh response to sea-level rise (ignoring any marsh accretion or other such response to a slow rise) (**Figure 7**).

At each marsh, digital photographs were taken of any unusual or interesting features, and a data packet was completed. The data packet consists of 8 pages (for the 'usual' marsh) or 9 pages (for the marsh with a perimeter + 40 elevation measurement). The first two pages consist of information such as a hand sketch of the marsh, the approximate location, date, marsh sequence or ID number, and brief comments about the marsh or surroundings. One page was derived indirectly from an assessment developed by the Massachusetts Office of Coastal Zone Management (Carlisle, 2004). This form was used previously by field teams from the University of New England (UNE) and the Wells National Estuarine Research Reserve (WNERR) in earlier marsh assessment work (Dalton et al, 2006, Morgan et al, 2007). It includes ratings (0 through 6) of the surrounding terrain in terms of land use, impervious surface, land cover, and drainage area; it also included marsh indicator ratings of erosion, vegetation, human impact, and tidal flow. Four additional data sheets contain ratings and factors copied from the Northern Ecological Associates (NEA) survey of the Presumpscot River, performed for the Casco Bay Estuary

Partnership. These assessments covered degradation (particularly from human causes), restoration estimates, and a number of factors reflecting ecosystem state. Not all areas of these pages applied to most fringing marshes. They had been designed more for riparian

or estuarine use, not specifically fringing marshes, but were appropriate in at least some marshes surveyed, so all factors were included to maintain compatibility between studies. Finally, one or two pages (two for the marshes at which elevation was taken) contained information about photograph IDs (if appropriate), GPS units used, the waypoints taken, and their purpose.

Data Processing and Analysis

GPS points taken in the field were used to create lines (in the case of boat survey transects) or polygons (in the case of field surveys) compatible with GIS software. Data sheets were scanned and their contents, in many cases, entered into spreadsheets. GIS themes were processed to determine overlap (for example, the overlap of image-based marshes and boat-transect-based marshes) and descriptive statistics were calculated for the underlying data.

Results

Image-Based Results

Approximately 1160 individual marsh 'units' were identified based on the image-based delineation. Each identified unit consisted of an area of wetland classified as one of the following types: high marsh, low marsh, mixed marsh, or invasive. Although areal measurement of these marshes was not one of the initial goals, the boundary of each marsh was outlined as closely as possible, allowing aerial estimation. The size-frequency distribution of marsh areas derived from the image-based marshes is shown in **Figure 8**. The smallest marshes found were approximately 10 m^2 in area; the largest were over 120,000 m^2. In many cases, fringing marshes

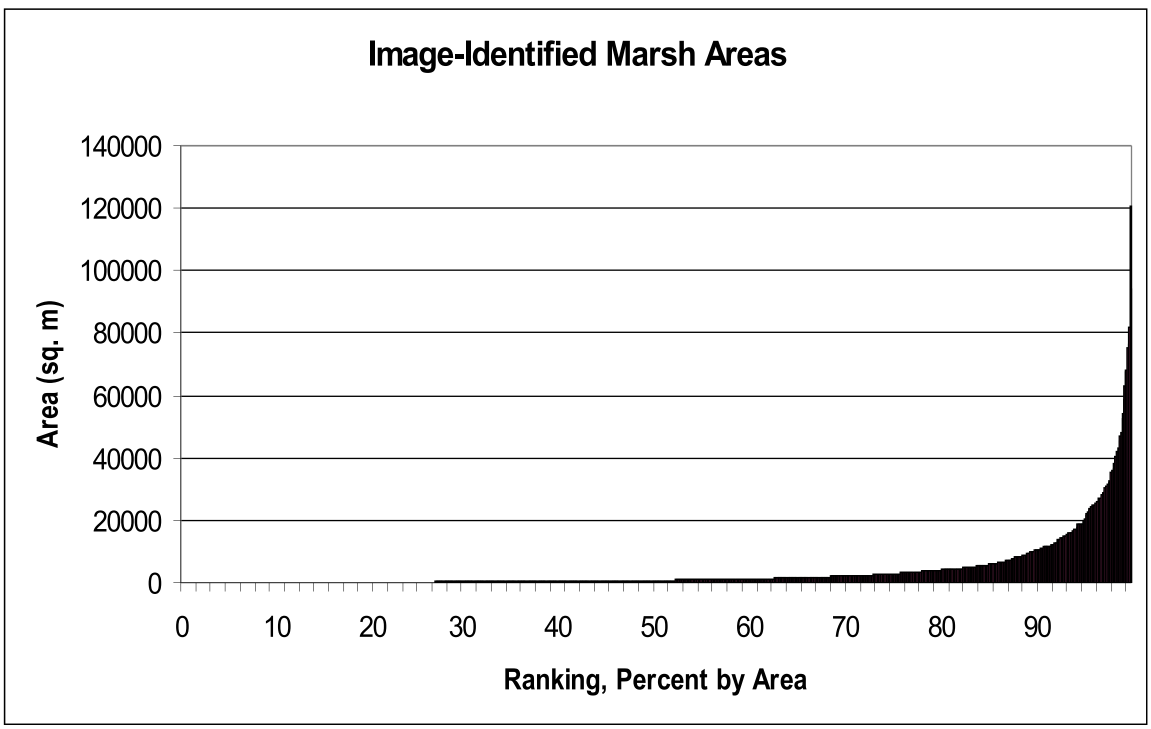

Figure 8: Image-based marsh areas in square meters versus ranking in percent.

began near the mouth of an estuary or channel, continued along the channel, and, at some point, transitioned to finger marsh and were not included in the data. The choice of this point varies, but the upper range of marsh areas is likely to be the result of fringing marsh contiguous with fluvial minor marsh (finger marsh). The majority of the marsh units identified were small: approximately 83% were 5000 m^2 or less.

A majority of the marshes were identified as the 'Mixed' type (including low and/or high marsh and, potentially, some amount of invasive) because boundaries between high and low marsh were difficult or impossible to discern from the imagery and all but large patches of invasive species might not be identified; but, for some marshes, further identification was possible (**Figure 9**).

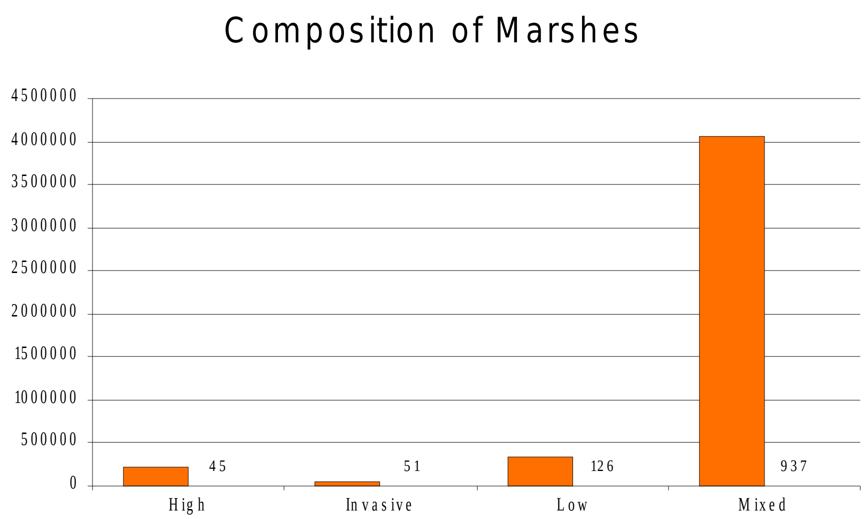

Figure 9: Distribution of photo-interpreted marsh units by area (area in m^2 shown on vertical axis) and count of each unit type (numbers beside bar along horizontal axis).

Each marsh unit was assigned the confidence level of the operator when delineating the marsh. Values ranged from 1 to 4, with 1 indicating the highest confidence and 4 the lowest (**Figure 10**). The distribution of confidence levels across marsh types showed a consistent pattern with most marshes receiving scores of 2 or 3. The diversity of indicators sometimes used to arrive at an estimate of the marsh boundaries and type means there is no means of determining correlations between types and confidence levels. In other words, our method does not allow us to address questions such as "*Is a high marsh identified with only a level 3 confidence sure to be a fringing marsh with confidence 1 or is it also only assured of being a fringing marsh (potentially with mixed high and low marsh types) with confidence 3*?". Identification as a fringing marsh and identification of type were not rated independently for confidence.

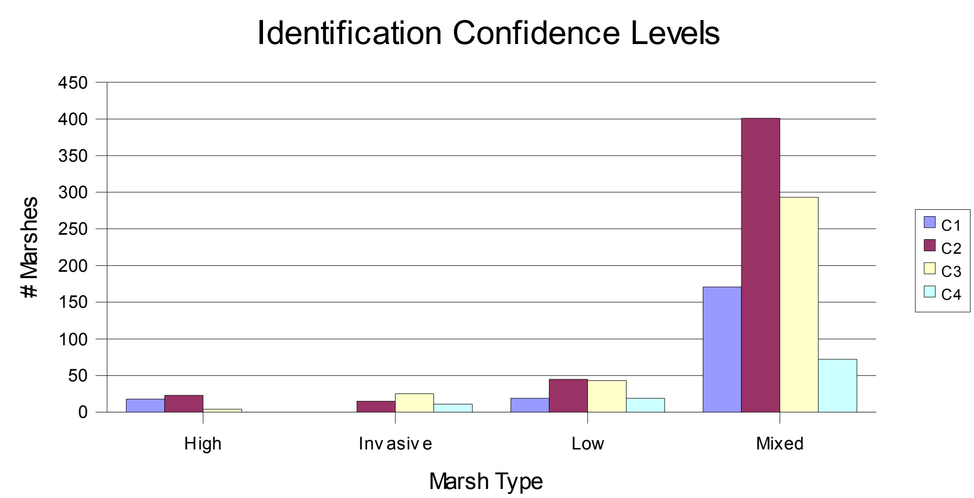

Figure 10: Confidence level distribution across marshes. C1 is highest confidence, C4 the lowest confidence.

Boat-and-Image Identification Comparisons

The boat transects resulted in approximately 500 buffered marshes that were compared to those identified through the imagery. Given that the boat survey marshes were marked during the summer of 2007 and the photo-interpretation images were taken in 2003, exact congruence was not expected. Also, observers from the boat were able to detect and mark marshes that would be invisible in any aerial imagery. Some marshes marked during boat transects were too small or sparsely vegetated to identify at the level of resolution available for this study; others were obscured from aerial view by overhanging foliage or other obstacles; finally, the boat enabled investigation of questionable patches of vegetation to verify the type. The comparison of the boat-surveyed marshes and photo-identified marshes is subject to error due to the change over four years, but the error is likely small relative to the error introduced due to limited resolution and clarity of the aerial photos.

Comparison of the two sets of marshes was accomplished by buffering the boat-surveyed marsh lengths (visible earlier as lines in the top image of **Figure 6**) with an elliptical polygon of a given radius (bottom image of **Figure 6**). These polygons were then tested for intersection (using a GIS program) with the polygons from the image-based marsh set. The result was the number of boat-identified marshes that were within the buffer radius of a marsh identified using the imagery – the accuracy of our marsh photo-interpretation can be estimated by using the fraction of boat-surveyed marshes that intersect with the photo-interpreted marshes. Obviously, the number of intersections increased as the buffer radius increased, so a range of radii were used to create a plot of the success rate as a function of buffer radius. Some minimum radius was necessary because the boat could often not approach closer than twenty or even forty meters to locate the actual submerged lower marsh edge, preventing estimation of the width of the marsh. Maximum buffer radius was arbitrarily chosen at 200 meters.

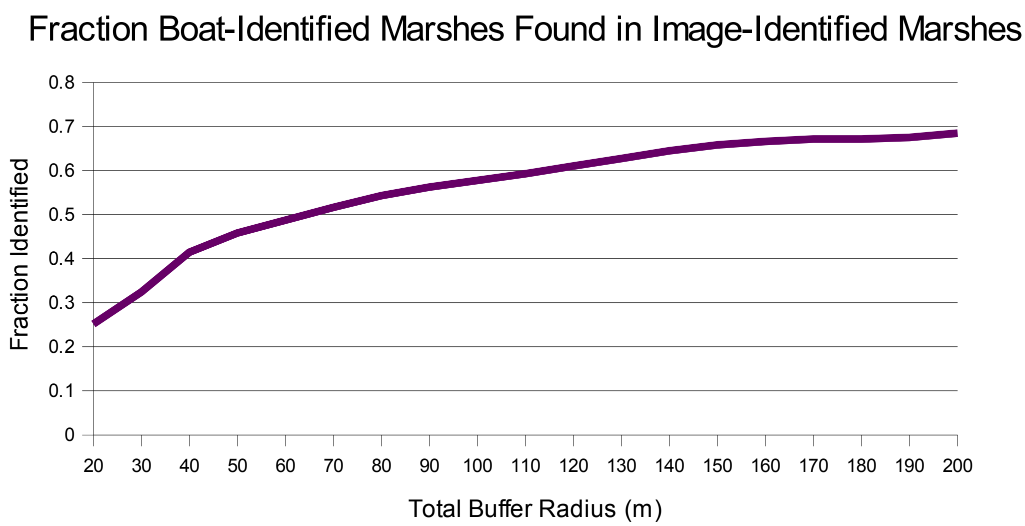

Figure 11: Fraction of the boat-surveyed marshes identified in the photo-interpreted marsh set as a function of boat-surveyed buffer width in meters.

The shape of the curve (which appears to approach 0.7 asymptotically as the radius increases) might be taken to indicate an upper limit of approximately 70% of the existing marshes identified (using a radius of 200 meters) from photo-interpretation. This could, in part, indicate the change in marshes between the two periods (in other words, approximately 30% of the existing marshes were not present – within 200 meters – four years earlier). In terms of accuracy of the image-based identification, the identification successfully found between 40%

and 65% (where the curve seems to level off significantly) of the marshes present, depending on the radius used to draw the ellipse used to create marsh polygons from the marsh length transects measured in the boat survey.

On-the-Ground Surveys

Field survey products included polygons resulting from in-the-field measurements of the marsh perimeter, the high-low marsh boundary, invasive patches, and the marsh perimeter at an elevation 40 centimeters higher than the existing perimeter (to estimate marsh migration).

Measurements of marsh areas (**Figure 12**) were limited at the upper end of the range because a maximum of approximately 300 meters of marsh length was surveyed. Measurement of marshes above this length (constituting approximately 8 % of the measured marshes) were truncated at approximately 300 meters of length. Consequently, area estimates for the larger marshes are less than the true marsh areas and descriptive statistics are biased lower than the true values. The average area was 3570 m^2 (with a standard error of 570 m^2); the median marsh area was 2055 m^2, while 80% of the marshes were of 5500 square meters or less. Approximately 46.5

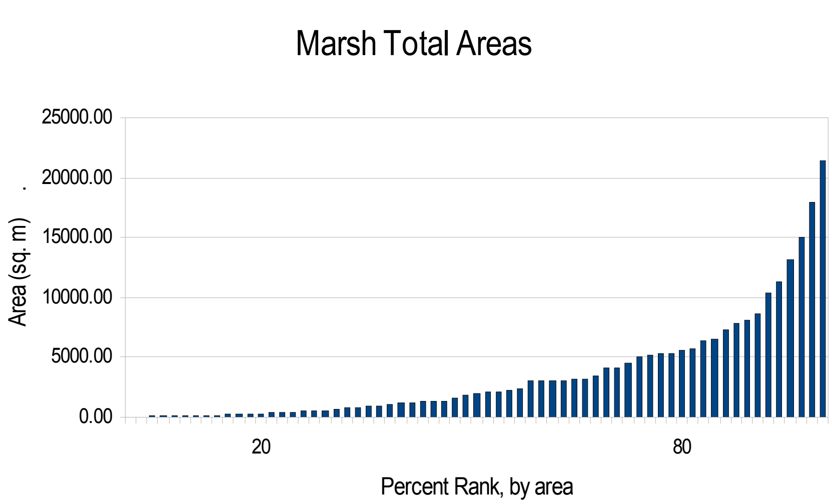

Figure 12: Surveyed marshes ranked by area.

percent of the total measured marsh area consisted of of high marsh and 53.5 percent of low marsh, with approximately 2 percent of the total marsh area covered with invasives (**Figure 13**).

At ten sample points (the original number of planned sample points, but not at all sixteen sample points for which field surveys were completed) additional measurements were made to estimate marsh response to a 40 centimeter rise in sea level. Two of these data sets (the GPS points taken of the perimeter at 40 cm higher elevation) were sufficiently corrupted that perimeters could not be determined. Total marsh area (as it presently exists) was generally larger than the new area estimated for a 40 cm rise in sea level. While a majority of the marshes lost area, the two larger marshes gained area. This pattern – a potentially shrinking area of smaller marshes, but potentially expanding area of some larger marshes with sea-level rise – was an apparent trend noted by the survey teams in several additional locations visited but not measured for elevation. This was a function of the upland slope, which tended to be steeper for small marshes, shallower for large marshes.

The measured marshes indicated a gain (5432 square meters) of marsh area after sea-level rise. The total gain in area was due to two larger marshes measured. Since they were randomly selected, this trend would result in a change in the landscape pattern of marsh distribution with small marshes shrinking and larger marshes expanding with a sea level rise.

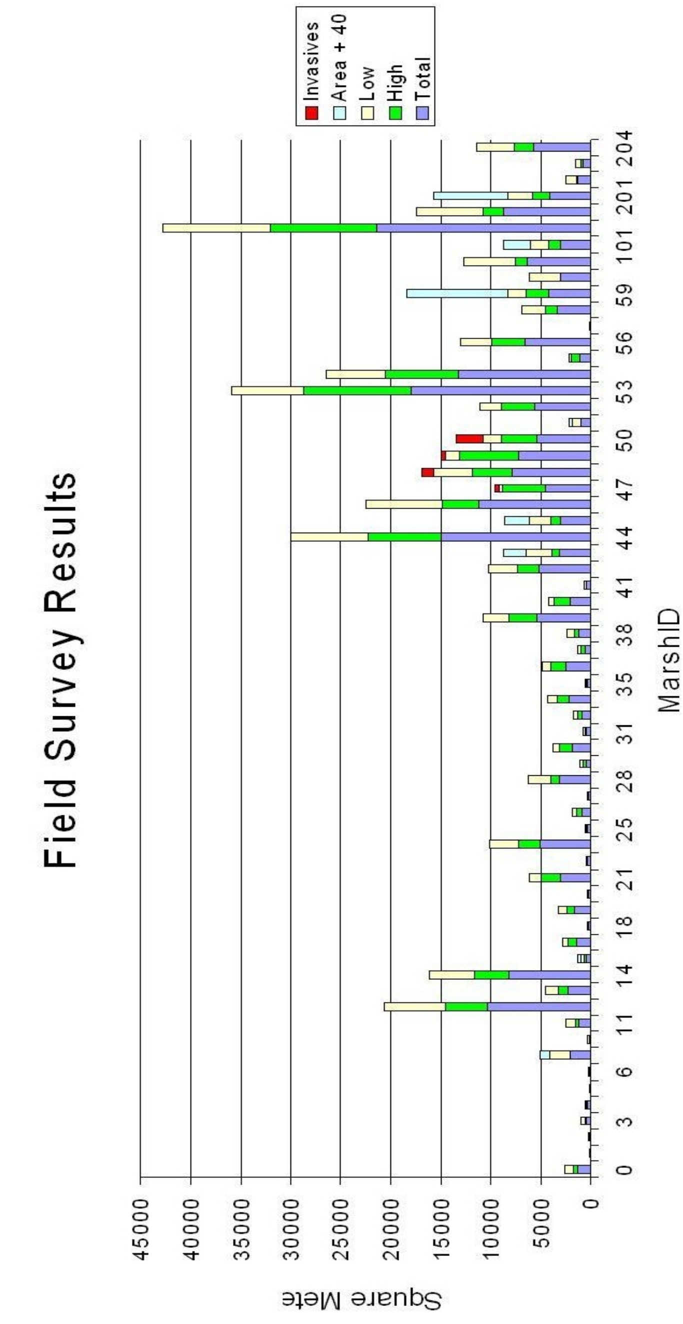

Figure 13: Marsh areas for all measured marsh units. Numbers along horizontal axis indicate marsh ID numbers from surveys: numbers less than 100 are from mainland surveys; 100 + numbers are from Cousins Island in Yarmouth; 200+ numbers are from Little John Island in Yarmouth.

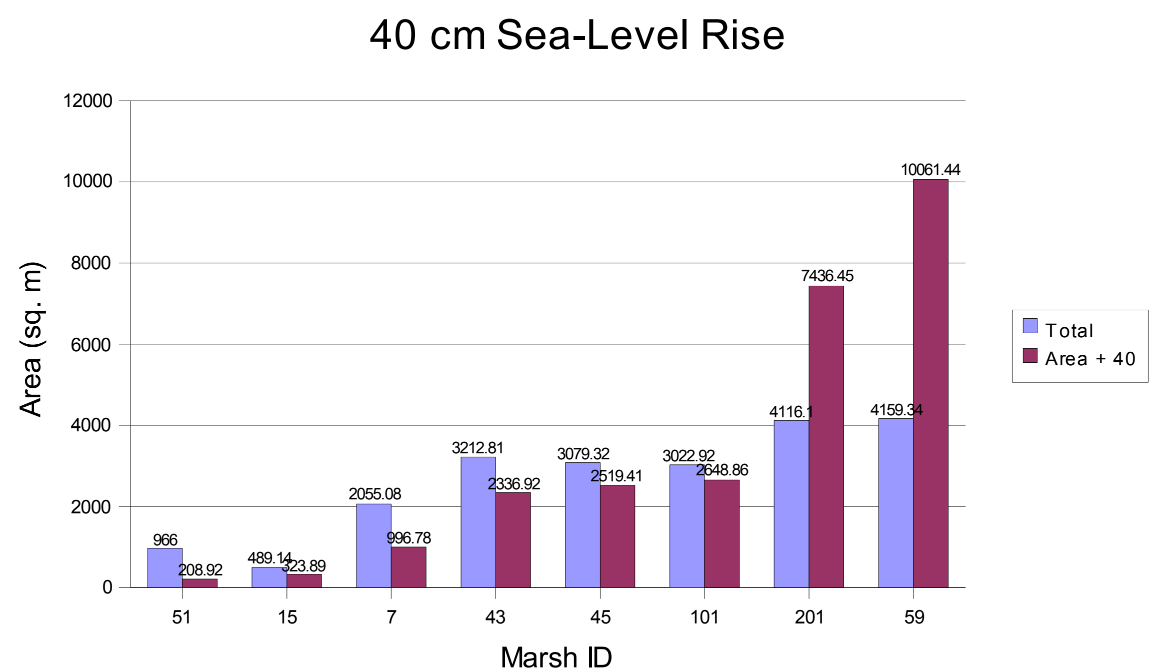

Figure 14: Total existing marsh area and estimated marsh area for 40 cm sea-level rise (both in square meters).

In addition to the GPS measurements of marsh perimeter, marsh condition was evaluated using the two protocols described previously (Table 1; example data sheets in the appendix). The MA-CZM protocol was first used to provide a 'rapid' assessment of marsh condition. A score of 100 % indicates a perfect rating in five categories of surrounding land use and cover, and eight categories of marsh status. Scores in each category ranged from 0 (extremely poor) to 6 (excellent), were summed and normalized by dividing by the maximum score (78) and converted to percentages. The NEA degradation score sheet (Northern Ecological Associates, Inc., 2005) rated fourteen categories of degradation causes (such as mowing of the marsh, invasive plant presence, pollution, and drainage) in a 'Yes/No' format, provided comment space, and rated another fourteen characteristics (low water quality, impediment to flow, and so forth) on a scale of 0 (no degradation) to 1 (high degradation) in 0.25 point increments. Because not all twenty-eight characteristics were applicable to fringing marshes, only twenty-three (fourteen factors causing degradation and nine marsh characteristics indicating ecological status) were used in determining the degradation score. The score was calculated by dividing the totaled degradation score for each marsh by the worst possible score (23 in the worst case); the most degraded marsh would receive a score of 1. Specific data for each marsh are available from the scanned data sheets and from spreadsheet tabulations of the results included in electronic format with this report.

Marsh #	Latitude (North)	Longitude (West)	MA-CZM Score (%)	Degredation Score	Marsh #	Latitude (North)	Longitude (West)	MA-CZM Score (%)	Degredation Score
00	43.72204	70.00203	60.3	0.26	31	43.88027	69.87352	94.9	0.00
01	43.72277	70.00200	46.2	0.26	32	43.87929	69.87381	80.8	0.30
02	43.75539	70.00755	57.7	0.39	33	43.87902	69.87370	89.7	0.04
03	43.75577	70.00762	60.3	0.09	34			94.9	0.00
04	43.75596	70.00774	83.3	0.17	35	43.86572	69.85412	73.1	0.00
05	43.75647	70.00835	69.2	0.09	36	43.86539	69.85373	92.3	0.00
06			43.6	0.65	37	43.86733	69.85313	83.3	0.17
07	43.75452	70.00603	65.4	0.39	38	43.85280	69.89868	76.9	0.26
08	43.75555	70.00527	50.0	0.30	39	43.85223	69.89805	84.6	0.00
09	43.75565	70.00500	57.7	0.26	40	43.85263	69.89928	88.5	0.09
10			46.2	0.26	41	43.85760	69.89931	87.2	0.13
11	43.75703	70.00305	43.6	0.35	42	43.85297	69.89938	71.8	0.35
12	43.75196	70.01604	56.4	0.13	43	43.81342	69.95943	66.7	0.39
13			85.9	0.13	44	43.81258	69.95894	76.9	0.00
14	43.75432	70.01547	87.2	0.26	45	43.70210	70.25425	50.0	0.30
15	43.81783	69.88580	67.9	0.17	46	43.70213	70.25420	43.6	0.00
16	43.81746	69.88602	56.4	0.22	47	43.70197	70.24311	64.1	0.22
17	43.81735	69.88615	60.3	0.30	48	43.70197	70.24313	76.9	0.09
18	43.81605	69.88642	73.1	0.09	49			53.8	0.52
19	43.81581	69.88663	70.5	0.13	50	43.70153	70.24278	66.7	0.30
20	43.49010	69.53160	79.5	0.17	51	43.86326	69.95036	71.8	0.35
21	43.81859	69.88602	89.7	0.00	52	43.86272	69.94932	73.1	0.04
22	43.82109	69.88468	91.0	0.13	53	43.86318	69.94801	85.9	0.09
23	43.83900	69.89177	82.1	0.26	54	43.82648	70.06587	67.9	0.39
24	43.83815	69.89246	50.0	0.17	55	43.82581	70.06897	73.1	0.30
25	43.83968	69.89083	78.2	0.09	56			78.2	0.04
26	43.83988	69.89070	92.3	0.04	57	43.86344	70.00240	66.7	0.04
27	43.84075	69.89038	92.3	0.00	58	43.86344	70.00232	85.9	0.00
28			92.3	0.00	59	43.86435	70.00240	84.6	0.17
29	43.88100	69.87358	100.0	0.04	60	43.86502	70.00108	88.5	0.00
30			89.7	0.09	61	43.86517	70.00095	88.5	0.22

Table 1: Marsh assessment sheets summary.

The average of the MA-CZM scores was 73.53%, while the average of all NEA degradation scores was 0.17.

The Restoration Priority List

The twenty-five most altered marshes, based on the MA-CZM score described above, were selected and evaluated further using the data collected so that basic restoration recommendations could be provided. The locations and ID numbers of the worst marshes are shown in **Figure 15**.

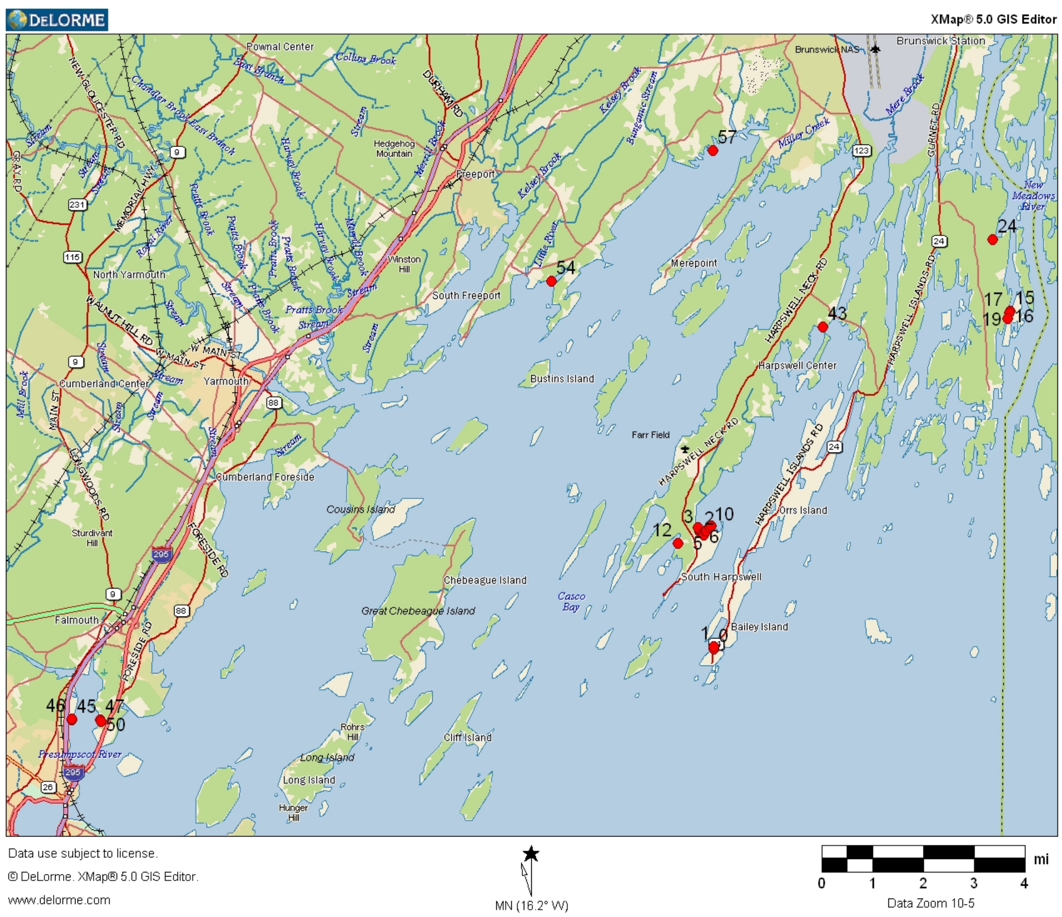

Figure 15: Map showing location and ID numbers for the 25 marshes rated worst according to the MA-CZM score.

Two of the 'worst' marshes were so small that their GIS perimeters could not be processed (the points overlapped with other points from the same or other marshes and were not plotted) and their areas were not calculated (but they would be in the single-to-low-double-digit numbers of square meters). For marshes that were sufficiently large to plot, areas, Marsh ID numbers (that can be related to ID numbers on data sheets, GIS files, and other data), the MA-CZM and NEA Degradation scores, a qualitative assessment (poor, fair, or good) of the marsh status, and suggested restoration efforts are shown in Table 2.

Table 2 begins... see description beneath last sheet of table.

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
11	43.6	0.35	NPS, lawn, erosion (boating?)	Steep slope from yard, armored bank/wall to yard, medium-density residential area, potential lawn chemicals, some boat mooring & boat ramp, sparse S.alterniflora	Because of the relatively high-density housing (for this area), it might be difficult to change much. A small veg. Buffer (garden? Shrubs? Along lawn) might reduce fresh/lawn chem. runoff, and removing/relocating moored boats would help reduce potential damage that results with low tide & boat movement, all with a reasonable level of effort.	1,241	Poor	Plant buffer, assess erosive impact of boat wakes
06	43.6	0.65	NPS, erosion (boating?)	Same neighborhood as #11, similar problems: lawn to shoreline, some armoring, septic?, bank/shoreline erosion, boat launch	Again, similar to #11, it would appear that some buffering might be possible between houses and shoreline, maybe some care w/boats in-out...	83	Poor	Plant buffer, assess erosive potential of boat wakes
46	43.6	0.00	NPS, lawn, Phragmites	Primary problem is the location. This is the marsh beside Route 295 in Portland, on the West side of the Presumpscot entry and bay. Road is often only 100' from water's edge, entire marsh is ringed on inland side (almost without break) by Phragmites.	Invasive control of Phragmites.	11,249	Poor	Reduce freshwater runoff to control Phragmites
01	46.2	0.26	NPS, lawn	High-to-medium-density single-family residential area, lawn nearly to waterline, marsh is also surrounded by bedrock and probably formed from ocean/runoff deposits of sediment. Little evidence of human degradation, but little chance of expansion or improvement due to location.	Not many choices. Location and nature of marsh ('bowl' in bedrock on 2 sides, rock wall on 1 side, ocean on final side) makes any changes difficult. Lawn area between house and cliff precludes much more buffer than already exists (some rosa rugosa and underlying grasses)	67	Poor	Drainage swale
10	46.2	0.26	NPS, lawn	Same area as #6 and #11 – medium-to-high density single family homes/vacation homes nearly on beach with lawn close to water's edge; obvious use is not heavy, but passive factors – lawn chemicals, and so forth are potential problems. Little/no buffer. Tiny marsh with non-discernible perimeter due to overlap/accuracy of GIS data points.	Small buffer (shrub?) between lawn and water might help reduce runoff somewhat. Education about boat storage and use to avoid damage to marsh might also be useful (no evidence of severe damage, but...).	<10	Poor	Plant buffer and/or drainage swale

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
08	50.0	0.30	NPS, lawn	Very small marsh patch in same area as #6, 10, and #11 – medium-to-high density single family homes/vacation homes nearly on beach with lawn close to water's edge; obvious use is not heavy, but passive factors – lawn chemicals, and so forth are potential problems. Little/no buffer other than vegetated hillside. Marsh size is so small that GIS did not provide accurate plot.	Steep grade from houses at top of 'hill' to water, but somewhat vegetated on slope... education about buffer importance wouldn't be bad... maybe some boat launch impact on small marsh.	<10	Poor	Plant buffer and/or drainage swale
45	50.0	0.30	NPS, lawn, erosion (boating?)	This is a marsh beside Route 295 in Portland, 1.3 miles N of Falmouth/Martin's Point exit. Phragmites present in abundance, appears to be fresh water inflow from drainage. Water edge of marsh is VERY irregular – breaking off in great 'chunks' (like calving of glacier), some of which are visible on mudflats beyond marsh edge.	Invasive control of Phragmites.	3,079	Poor	Reduce freshwater runoff to control Phragmites; assess need for erosion control
24	50.0	0.17	NPS, erosion (boating?)	Sparsely residential, mostly forested shoreline, two small freshwater streams empty into marsh, one dwelling sitting close to marsh. May be some peat erosion along edge of marsh (not terribly obvious, but possible).	Could potentially use some additional buffer between the house and marsh, but, otherwise, is good. The rating here may be a little low (MA-CZM).	5,059	Poor	Expand buffer, assess need for erosion control
49	53.8	0.52	NPS, trash/debris, Phragmites, tidal restriction, nutrients, erosion	This is the marsh in Falmouth, just inland of the Route 1 bridge from Martin's point, near a red house on north side of Presumpscot bay/estuary. Much human 'trash' and building remnants that could be cleaned up. Phragmites in connected impoundment. Large section of fringe marsh appears 'dead' in that little S.alterniflora is growing, but peat exists, covered with algae or other green growth. Peat is breaking in large pieces, eroding away.	Clean up of 'trash' wouldn't hurt any (large, decaying boards, some partially silted piles of old trash, bottles, tires...). Phragmites reduction/control. House (red) is literally 'on' the water (old commercial building? Possibly historical?) with little chance of buffer where one doesn't already exist. Other houses atop steep bank with lawn often to bank top. Some erosion due to use (paths, docks evident). 'Dead' marsh problem unknown...	7,263	Poor	Improve tidal flow to control Phragmites; drainage swale to reduce NPS, eliminate/ alter access paths
12	56.4	0.13	NPS, impervious surface	Low-medium residential in surroundings, mostly buffered, several dock structures in marsh area (some raised, some not), roof & driving surfaces increasing runoff.	Some buffer additions might be possible, education on use of lawn chemicals could be beneficial, dock removal or modification would be helpful.	10,353	Poor	Slow release rain barrels, drainage swales

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
16	56.4	0.22	NPS, tidal restriction, lawn	Located on side of channel between two islands, channel divided by embanked roadway with bridge restriction (as in #17) Small marsh formed by sediment deposits in rock outcrop depressions. Forested surroundings, houses > 100' up relatively steep slope. Some potential for runoff, but minor.	No real recommended changes. Education to promote maintenance of full forest buffers might help maintain status.	441	Poor	Expand buffer if space allows, or add drainage swales; assess value of tidal restoration
02	57.7	0.39	NPS, impervious surface, lawn	Same area as #6 through #11 – medium-to-high density single family homes/vacation homes nearly on beach with lawn close to water's edge; obvious use is not heavy, but passive factors – lawn chemicals, and so forth are potential problems. This particular marsh lies at the base of a steep slope w/various growth (primarily grasses, low shrub) to lawns above. Road to boat ramp runs down long hill directly into mud flat w/no means of controlling runoff, road/unknown water drain.	Again, education about lawn chemicals, buffers, runoff, and effects on marsh/coastal environments might be useful, encouragement to plant more significant (especially woody, non-grass, dense shrub for better year-round runoff velocity reduction on hillside). Additional 'flow directors' on roadway might reduce freshwater flow during heavy rain (potentially), nearby drain of freshwater could be removed (small source during our visits, but might run faster/greater volume during heavy storms?).	90	Poor	Drainage swale/diversion for access road, slow release rain barrels, expand buffer
09	57.7	0.26	NPS, lawn, hardened shore	Same area as #6 through #11 – medium-to-high density single family homes/vacation homes nearly on beach with lawn close to water's edge; obvious use primarily moored boats and some debris (sticks) along edge – lawn chemicals, and so forth are potential problems. Marsh lies at the base of a steep slope w/little growth (some grasses) to lawns above; rock armoring and wooden barricade wall at base of slope. Owner states that marsh is 'new' in last few years – possibly due to sediment from bank?	Could probably use better buffering between lawn and top of slope, and on slope itself. Some debris cleanup between marsh and slope base. Boat mooring could possibly be changed to better avoid marsh. Education might be beneficial and sufficient to make changes.	141	Poor	Expan buffer, assess erosive potential of armoring and mooring

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
17	60.3	0.30	Tidal restriction, possible NPS	Roadway crossing channel between islands, possibly some flow restriction by bridge only at highest tides, steep slopes (tend to be forested, but not always for full 250' radius), narrow marsh peat area at base of slope, use (minor, path, some marsh damage) by local shell-and-worm harvesters evident, possible lawn chemical/septic?	Flow restriction appears of low priority (channel open at both ends, restriction probably minor except for very high tides), some construction lacking ground cover (lawn or otherwise) probably a matter of time, generally good buffer (forested) but education might be useful to maintain buffer. Use (harvesters) is not heavy enough to cause major problems, but a posting of guidelines for use posted nearby (or other educational outreach) might be helpful.	1,391	Poor	Assess value of tidal restoration, maintain buffer
00	60.3	0.26	NPS, lawn, yard waste, armoring	High-to-medium-density single-family residential area, lawn nearly to waterline. Raised dock at edge of marsh probably has little detrimental effect. Surrounding yards to within 5' of drop from raised upland to marsh peat, buffer of rosa rugosa of 2-5' in some places (not all), some debris (lawn waste). dumping evidence, some armoring along rise to lawn.	Residents could create a wider buffer between open lawn and marsh. Slope is nonexistent (sharp transition of 1-4' vertical drop) between lawn and marsh, flat-to-slight slope to house and roadway (close to opposite sides of houses). Not a lot of room for improvement other than habits a some landscaping. Education about lawn chemicals, dumping, buffers might be useful to promote those habits.	1,274	Poor	Expand buffer, remove yard waste, assess erosive potential of armoring
03	60.3	0.09	NPS, lawn, erosion	Same area as #2 through #11 – medium-to-high density single family homes/vacation homes nearly on beach with lawn close to water's edge; obvious use is not heavy, but passive factors – lawn chemicals, and so forth are potential problems. This marsh also lies at the base of a steep slope w/various growth (primarily grasses, low shrub, some trees) to lawns above; more forested than previous marshes. Some bank erosion evident.	Buffer improvement and bank stabilization (where appropriate). Again, education on buffers, lawn chemicals might be useful.	473	Poor	Plant buffer, assess need for erosion control
47	64.1	0.22	NPS, lawn, impervious surface, Phragmites	Between 'Foreside Commons' and Gilsland Farm in Falmouth, lining NW side of small stream, multiple patches of Phragmites, some narrow buffer (<50' noted) between lawn/housing and marsh, potential for lawn chemicals (condo maintenance?), runoff from drives, roofs.	Invasive control, improved buffer, education of residents & management.	4,572	Fair	Expand buffer, add drainage swales, control Phragmites

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
07	65.4	0.39	Freshwater runoff	Same area as #2 through #11 – medium-to-high density single family homes/vacation homes nearly on beach, but this marsh has some forested buffer between it and buildings, very little lawn draining directly into marsh area (a small amount at each end). Freshwater spring or seep evident from base of small ravine through forested area, fresh/drain water pipe near one end (between this marsh and #2 above). Some debris in marsh (old dock pieces, general trash).	Buffer improvement possible in some areas (small amount of the upland edge that is against lawns), some debris in marsh could be removed.	2,055	Fair	Expand buffer, investigate drainpipe
43	66.7	0.39	NPS, lawn, buffer alteration	Short part of a larger marsh (separated from 44 for elevation measurements). Shoreline mostly forested, medium-steep slope; Steep slope to marsh in front of house looks to be recently cleared of shrubs and partially replanted. Could possibly use more veg coverage. Some ridged mussels in silt.	Buffer/slope vegetation might be improved along steep slope area.	3,213	Fair	Improve/ expand buffer
50	66.7	0.30	NPS, invasives, foot traffic, watercraft storage	Similar area as #47 along waterfront of 'Foreside Commons' in Falmouth. Narrow buffer to small lawns to buildings (condominiums), Some invasives – Phragmites, cattails, Japanese knotweed along shore and up small freshwater stream from saltwater. Minor evidence of marsh use: kayak moored off shore and some trash in/along marsh (washed up).	Invasive control of Phragmites and other invasives, improved buffer, education of condo management/landscaping service re chemicals & fertilizers might be a good step. Minor marsh cleanup could be helpful.	5,370	Fair	Expand buffer, control invasives, remove watercraft from marsh
57	66.7	0.04	Natural ledge	Small marsh, seems to have formed by sediment deposit in 'bowl' of rock.	Not a lot to suggest on this one. Score reductions are primarily because of surrounding rock.	51	Fair	Maintain buffer
15	67.9	0.17	Shallow upland soils, wastewater treatment method not apparent	Extremely tiny marsh on an only-slightly-larger island with a tiny house immediately adjacent to marsh. The house seems not to have a septic system (maybe a composting toilet?). Bedrock under only shallow soils, marsh is forming in low bedrock pockets of sediment deposit.	No good suggestions. House might be inspected for septic and recommendations based on that. Owner is a bit eccentric, but seemed environmentally oriented. There may be nothing to do but leave the marsh to do as it will...	489	Fair	Maintain buffer, assess wastewater disposal

Marsh ID	MA-CZM Score (%)	Degredation Score (0-1)	Primary Impacts	Problems Noted	Recommendations	Area (m2)	State*	Restoration Action
54	67.9	0.39	Bank erosion, foot traffic	This is a long marsh at the foot of a steep slope on top of which is the Recompense Campground in Freeport. There are campsites, toilets, and several houses at the top of the slope, but the hillside is fairly well-forested in most locations (some exceptions occur where the growth is younger and/or additional buffering might be beneficial). Some bank erosion is evident, but is often from high seawater levels. Some marsh use by campers is evident, but damage is minimal to non-existent.	Some additional buffer might be useful in a few isolated locations. Erosion should be checked and monitored, potential septic problems monitored.	13,196	Fair	Maintain buffer, protect marsh from foot traffic, assess need for erosion control
05	69.2	0.09	NPS, lawn	Same area as #2 through #11 – medium-to-high density single family homes/vacation homes nearly on beach. This very small marsh lies at the base of a steep slope from houses and lawns above.	Buffer improvement possible in some areas & education of ownsers above .	25	Fair	Expand buffer
19	70.5	0.13	Bank erosion, foot traffic, watercraft storage	This is in the same area as #15, #16, and #17: a channel split by a road w/bridge. Relatively steep, forested slope to marsh, which has formed in sediment (unclear whether from upland erosion or deposition from tidal flow/wave motion, although some bank erosion mentioned), minor human use (canoe storage/launch).	Not a lot to suggest here. Little impact, good buffer. As in other areas, because houses are new, education might be good to ensure care of buffer and minimization of avoidable impacts.	1,621	Fair	Assess need for erosion control, remove watercraft from marsh

Table 2: Twenty-five worst marshes (based on MA-CZM score), impacts and problems noted, and recommended actions. NOTE: In many cases bank erosion may be an important source of sediment that allows the fringing marsh to increase in elevation in response to sea level rise. Bank erosion due to natural wave action is a normal process providing sediment to adjacent marsh. Wake energy from boats can greatly increase erosion however, as can removal of stabilizing bank vegetation, and hardened shorelines adjacent to natural shorelines. Increasingly severe storms related to climate change may lead to excessive erosion, but until this has been documented for the Gulf of Maine, it is best to assume that erosion occurring in the absence of any direct human activity is natural and beneficial for the marsh.

Assessment Recommendations

Our field survey indicates that the vast majority of moderately to heavily impacted marshes that were visited suffered from insufficient buffers (**Table 2**), with the likelihood that nutrients and chemicals (especially those used to maintain the lawns that almost always exist in these locations) flow into the marshes with the heavy freshwater runoff. A secondary problem is physical use and damage to the marsh from activities such as dock movement, boat storage, boat wakes, and foot traffic. Finally, phragmites *(Phragmites australis*) and, to a far smaller extent, purple loosestrife (*Lythrum salicaria*) appear in a very limited number of locations (although some locations do represent large areas of phragmites, relative to potential marsh size).

Potential solutions to both human problems involve, first, outreach and education. Although there appeared to be a great deal of enthusiasm from the general population we met for our marsh surveying efforts, and even apparent support for protections of the existing marsh, there was also obviously a significant lack of understanding of salt marsh functions and values, and human-mediated factors that can affect their health and existence. Education and outreach can reduce these obstacles to marsh recovery and protection.

However, education – knowledge – is seldom sufficient to change the habits of a majority of the general population. Incentives – the 'stick or carrot' approach – are often required. These might take the form of more stringent policies and restrictions on landscaping, but this is likely to only affect areas (and marshes) in which development at the shoreline has not already occurred – locations already imposing negative impacts on existing marshes are likely not to be required to retroactively modify landscaping or activity to meet new regulations. Additionally, there may be a social 'backlash' to any externally-imposed landscaping requirements that might eliminate the good will that our survey team found to exist. In these cases – where homes are located very close to the water's edge and landscaping predates the existing shoreland protection laws – homeowners could be encouraged to plant buffers on the sides or backs of their lots (opposite the water) to reduce total runoff. Also, many lots were located on steep banks that could be re-vegetated to provide better marsh protection without interfering unduly with water access or views.

Perhaps a form of reward, either social, financial, or a combination, might be instituted, potentially in combination with policy reform. A social marketing effort could dovetail nicely with an outreach and education program to encourage participation of local residents in efforts to 'protect their fringing marsh' or to improve landscaping and coastal activities in general. If possible, small tax incentives or other financial assistance (combined with socially-based rewards such as decals, mention in local papers, and other obvious 'honors' for participation) might be used to encourage and increase the effectiveness of any such program.

The community(ies) of the area – particularly in the eastern study area – appear to be well-educated and socially-minded. Although we didn't have the time or resources for a program of the type required, for example, the local television station in Harpswell (carried on cable and low-power broadcast to those areas lacking cable) seemed willing during our survey to run one or more educational stories about the fringing marshes, and might be willing to participate in a more sustained program. Similarly, the possibility exists to invite organizations and businesses (particularly local landscaping, agricultural, hardware businesses, and non-profits) to participate in the program, possibly offering small discounts – economic incentives – for purchases to be used in support of the marshes and helping to distribute any indicators (decals for windows or doors, for example) that publicly recognize participants – the 'social carrot'. Obviously, these are simply a few of the possible ideas, but such a program could potentially produce significant changes in human activity occurring on the marshes without major financial commitment.

Although invasive treatment in some areas (the marshes in Falmouth along the Presumpscot River come to mind) is best left for well-trained professionals, invasive education should be part of any project, to include identification keys to the invasives found and means for removal by the layperson (if feasible) or contacts for professional assistance. With a small cadre of well-trained managers, this might also be incorporated into a social program to restore and protect fringing marsh in Casco Bay – providing a social activity for occasional weekend meetings, for example.

Although the survey team encountered overwhelming support among the coastal inhabitatns we met, it might be advisable to obtain an independent and more accurate estimate of the population's endorsement of any program considered. In this regard, a mail, telephone, or internet-based survey (or a multi-mode survey incorporating two or all the means) of a sample of the area residents to estimate support for such a program and the effectiveness of potential incentives would be advisable prior to implementation. A properly conceived and implemented survey could provide an estimate of actual support for any envisioned program to improve marshes as well as a means for 'fine tuning' details of any such program to best mesh with the attitudes, desires, and abilities of the population. It could also provide the introductory event for any program to follow and allow for community input and involvement in the program at an early stage.

A final component of any future efforts in support of fringing marshes would be a monitoring program. Although this project has provided a solid estimate of the location, size, and state of the fringing marshes in Casco Bay, it is limited. Field visits were made to only a small fraction (less than 10%) of the photo-identified marshes and could only provide a 'snapshot' of these marshes. However, much of the work performed by the survey crew – the assessments, for example – could be performed by laypeople under the guidance of more experienced leaders. This could be a continuing effort that would provide an ongoing means of assessing the general trajectory of fringing marshes in Casco Bay. The Casco Bay Estuary Partnership and the Wells NERR appear to be well suited to collaborate on and coordinate such an effort, including data and information management, analysis, and distribution. Other environmentally oriented non-profits, such as Friends of Casco Bay, the Maine Audubon, and similar coastal-oriented groups also comprise potential partners in this effort.

Products and Deliverables

This report represents the primary project deliverable. The data sets collected are another important deliverable/product, producing baseline data and information describing marsh distribution and condition with which to assess future change. The image-based marshes identified in Casco Bay have been collected in a single GIS shape file compatible with a number of GIS systems. This provides the location, polygon outline, area, and estimated type of the marshes identified and will allow the use of this information for future monitoring and estimation purposes. Survey marsh locations and the GPS results are similarly included in a second GIS shape file. Metadata are provided. Scanned field survey assessment sheets and associated spreadsheets are provided in digital format along with the photo-documentation. An HTML-based means of viewing most of this information is provided, along with an instructional file explaining the content and navigation. Finally, the raw data is provided where appropriate.

In Conclusion

The mapping of marshes using the DeLorme Topobird imagery identified between fifty and seventy percent of the marshes identified in the same areas via boat survey. Considering the difference in time between the two surveys (2003 and 2007), the accuracy was good. Supporting this was the fact that areas of the image-delineated marshes followed closely the areas of the surveyed marshes (both sets of marshes showed that approximately 80% of the marshes were under 5000 square meters in area) even though determination of area and boundaries was not initially part of the image-based effort and there was no means of more precisely comparing results. The complexity of coastal vegetation, abundance of shadow, and similarity of image signatures (e.g. colors) for different habitats provided a difficult environment for this type of effort (as described previously), but the technique appears to provide a reasonable result for the effort involved (assuming high-quality imagery is available).

A simple calculation of the average marsh area (determined from the field surveys, the most accurate source) of 3570 square meters and the number of marsh units found, 1160, would provide an estimate of approximately 4.14 square kilometers, 41.4 hectares, or 4,141,200 square meters of fringing marsh along the mainland coast of Casco Bay, with a total linear extent of nearly 150 km of fringing marsh. The initial estimates of sea-level rise adaptation of fringing marshes appear encouraging, but may indicate a change in landscape type (shrinking small marshes and expanding larger marshes). The average of the MA-CZM scores was 73.53%, while the average of all degradation scores was 0.17. This would indicate that there is room for improvement – the fringing marshes of Casco Bay are not in pristine shape. Encroachment by development and other factors – mostly anthropogenic – are harming fringing marshes.

However, some marshes appear to be doing well, as evidenced by the many high MA-CZM and low degradation scores. An encouraging sign was the acceptance and support by nearly all the residents with whom the survey team met. In general, those who lived near the fringing marshes surveyed appeared to have some appreciation of the importance of the habitat, and the need to assess, and then improve and protect, these ecosystems. Although a very early and anecdotal indicator, the spirit with which this effort was met by the local residents indicates an optimistic prognosis for any future effort to improve and protect the fringing marshes in Casco Bay.

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Appendix

Field Assessment Sheets

Casco Bay Fringing Marsh Field Survey Marsh ID LJ - 1

Date& Time: 8/22/07 Evaluator(s): Kristin & Rachel

Location: Lat 43.75630 Long 70.13592

Description of Location: Little John Island

Elevation profiled? Yes ☒ No ☐

Invasives profiled? Yes ☐ No ☒

Salinity (refractometer)

#	Description/location	Salinity
	32 ppm	

Comments:

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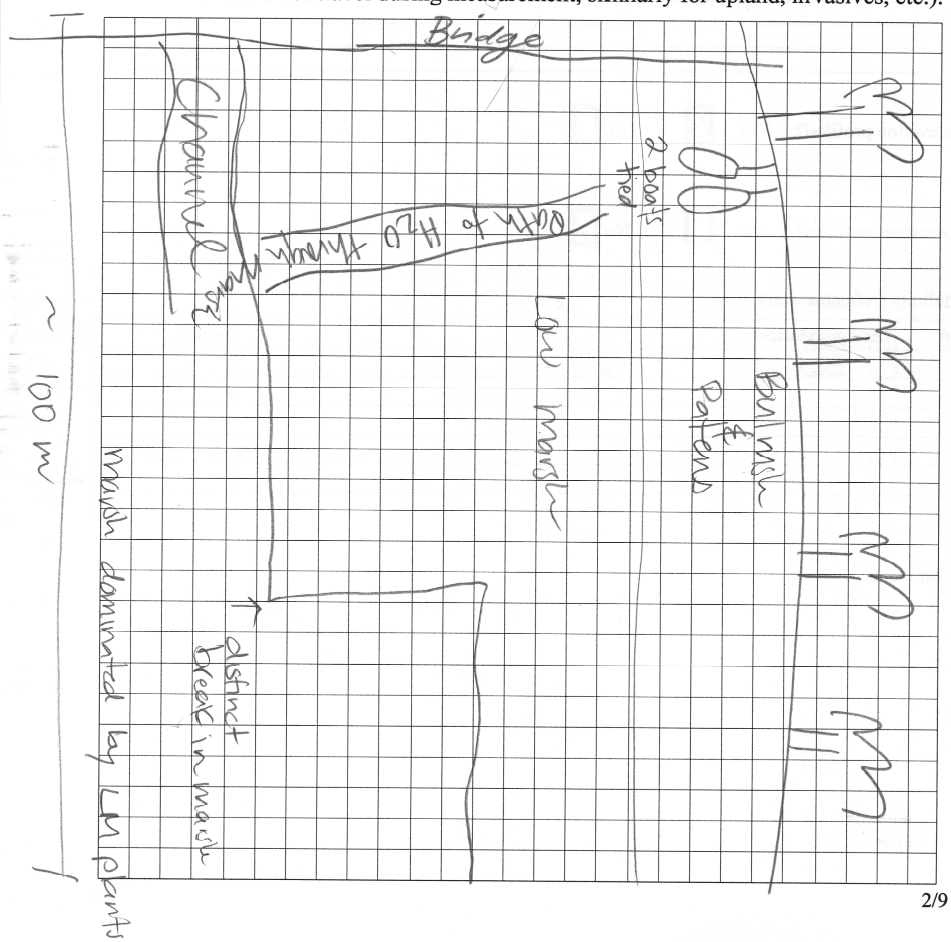
Casco Bay Fringing Marsh Field Survey Marsh ID LJ-1

Average Estimated Bank Rise Angle: 0-10° | (10-25°) | 25-45° | 45-65° | >65°

(use inclinometer)

Sketch of marsh with approximate location and size of notable features (invasives, restoration possibilities, etc.) indicated. Also indicate direction of boundary measurement (ie, show a line across the marsh at approximate high/low boundary with arrows for direction of travel during measurement, similarly for upland, invasives, etc.).



Casco Bay Fringing Marsh Field Survey Marsh ID LJ-1

MA-CZM Marsh Assessment Form

Scoring Criteria	5-6	3-4	1-2	0	Score:
Landscape					
Dominant Land Use	Forestry & Open Space	Low-density residential or grazing	Medium-high density residential	Commercial, industrial, transportation	4
% Impervious Surface	< 5	5-10	11-20	>20	4
% Natural Vegetation	>50	30-50	10-29	<10	4
Ratio of wetland/Drainage Areas	>10 %	6-10 %	2-5 %	<2%	3
Possible major sources of pollution	None discernable	Septic sewage effluent	Fertilizers/pesticides from golf, lawns, ag.	Industrial/Commercial effluent	3
Salt Marsh					
Tidal Fluctuation & Degree of Flushing	Unimpeded natural tidal surges	Some artificial control & modification to natural flow	Flow controlled by constriction of outlet or shoreline modification	Salt marsh cut off from normal flow	5
Outlet Restriction	No Restriction	Restriction > 30'	Restriction 5-30'	Restriction < 5'	3
Rate of Erosion	No erosion evident	Bank erosion (slumped, thin grass, disturbed)	Bank eroding, well established process	Severe erosion	3
Nature of Substrate at Water-Substrate Interface	Sand, silt/mud, or mixture	Predominantly sand, silt/mud with organic material	Predominantly organic peat with some sand, silt/mud	Predominantly rocks, cobbles, or peat	5
Vegetation Diversity (aquatic bed, emergent, scrub/shrub, forest)	4 Classes	3 Classes	2 Classes	< 2 Classes	6
% of Edge Buffered to 100'	> 80 %	50 – 80 %	20 – 49 %	< 20 %	2
Food Sources	Abundance of macrophytes, algae, periphyton, CPOM, FPOM	Some macrophytes, plus algae, periphyton, CPOM, FPOM	Some algae and periphyton, CPOM, FPOM	No macrophytes, algae, periphyton, some CPOM, FPOM	5
Degree of Human Activities in Marsh	No impact.	Low level use with minimal impact.	Moderate use, erosion noticeable, some vegetation degradation.	High use, severe degradation	3

Score: $\frac{(\sum of\ Scores)}{78} x100$: ~~49/78~~ 50

3/9

Casco Bay Fringing Marsh Field Survey Marsh ID LJ-1

Degradation Scoring

Restoration Need:	none needed. Someone could talk to guy who keeps his boats on the marsh.
Description:	

Source or Cause of Degradation (circle applicable)

1	Rip-rap or other armoring N		8	Dam/obstruction or other obstacle (breakwater, dock, etc) N
2	Fill/debris/trash/dumping N		9	Land clearing (not right-of-way related, such as view) Some
3	Drainage (such as freshwater drain) N		10	Right-of-way clearing (road, boat access, etc.) yes
4	ATV/Off-road damage N		11	Unstable bank N
5	Culvert y - not bad		12	Land use resulting in pollution/nutrient input yes
6	Invasive plant N		13	Mowing or other maintenance issue no
7	Impervious surface N		14	Erosion creating marsh N

Indicators of Degradation (impact/severity, 1.0 = very high, 0.75=high, 0.5=moderate, 0.25=low

Indicator		Score	Comments
1	Low water quality	0	
2	Impediment to natural flow	.25	
3	Obstruction to fish passage	0	
4	Low bank stability/erosion	0	
5	High velocity runoff (gullies, etc)	0	
6	Lack or impaired vegetation	0	
7	Unnatural channel	.5	
8	Repeated/severe flooding	0	
9	Unnatural sediment buildup (hindering marsh growth)	0	
10	Impaired aesthetic quality	.5	
11	Vegetated buffer < 250 ' wide	.75	
12	Potential pollution/nutrient influx	.5	
13	Wetland loss	0	
14	Substrate disturbance	0	
Total Degradation Score		2.5	

Casco Bay Fringing Marsh Field Survey Marsh ID LJ-1

Conceptual Costs

Low	< $25,000
Medium	$25,001 - $75,000
High	$75,001 - $150,000
Very High	> $150,000

none needed

Checklist of factors contributing to cost (check applicable factors)

1	Planting/Landscaping	
2	Invasive Species Control	
3	Soil Amendments	
4	Soil fill/removal	
5	Biostabilization/erosion or sediment control	
6	Hard structure stabilization	
7	Soil stabilization/erosion control	
8	Minor grading	
9	Major grading	
10	Impervious road surface	
11	Remove/modify areas of concentrated runoff	
12	Construct storm water management device	
13	Construction access	
14	Trash/debris removal	
15	Construct recreational facilities/access	
16	Removal of obstructions	
17	Clearing and grubbing	
18	Mobilization/demobilization	
19	Maintenance	
20	Exclusion devices/Animal control	
21	Engineering Designs	
22	Topographic surveys	

Comments: talk to guy who keeps boat on marsh.

V

45044

Casco Bay Fringing Marsh Field Survey Marsh ID________________________

Supplemental Evaluation Forms

Channel/Bank Morphology Parameter		0	0.25	0.5	0.75	1	Estimated Area (m^2)
1	Undercutting of banks/high flow	None	≤10 %	10 – 20 %	20 – 40 %	> 40 %	
2	Erosion of banks from upslope runoff	None	≤10 %	10 – 20 %	20 – 40 %	> 40 %	
3	Steepness of banks (inclinometer)	0 - 10°	10 - 25°	25 - 45°	45 - 65°	> 65°	
4	Percent of banks covered with persistent vegetation	≥50%		25 – 50%		< 25%	
5	Evidence of severe scouring	None	≤10 %	10 – 20 %	20 – 40 %	> 40 %	
6	Aggradations of sediment in waterbody	No Impairment		Moderate Impairment		Significant Impairment	
7	Evidence of significant increase in flood flow (floodplain flooding > every other year, bank and channel erosion, mid-channel bars, slumping, incising)	None	Minor impact			Major Impact	
8	Evidence of a significant decrease in flood flow (Channel widening and shallowing, channel braiding, excessive sediment buildup on outside bends)	None	Minor Impact			Major Impact	
9	Evidence of channelization, loss of sinuosity	None	Minor Impact			Major Impact	
10	Bank erosion creating/contributing to marsh	None	Stable bank/marsh			Unstable or attempted abatement	
In-Stream/Fish Habitat Parameter		**0**	**0.25**	**0.5**	**0.75**	**1**	
1	Impediments/obstructions to fish passage present in waterbody (culverts, dam/weirs with fish passage devices, log jams...)	None		Impedes passage		Obstructs passage	
2	Average late-season pool area	35 – 65%		> 65%		< 35%	
4	Presence of in-water attractors (logs, brush, rocks...)	15 – 50% NA		>50%		< 15%	
5							
6							
7							
8	Percent aquatic/intertidal vegetation	≥50%		25 – 50%		< 25%	
9	Restriction to shoreline breeding/foraging habitat	None		Minor		Major	
xx	Substrate (info only)		Gravel/rubble	Sand	Bedrock	Silt/clay	

Casco Bay Fringing Marsh Field Survey Marsh ID______________________

Human Disturbance		0	0.25	0.5	0.75	1	Estimated Area (m^2)
1	Evidence of periodic direct disturbance (ATV, livestock, mowing/cutting, boat landing...)	None		Minor		Major	
2	Evidence of periodic disturbance in water body (ATV, boat landing, livestock....)	None		Minor		Major	
3	Evidence of trash, debris, hard structure in waterbody	None		Minor		Major	
4	Evidence of trash, debris, hard structure on shore/bank	None		Minor		Major	
5	Presence of commercial/industrial activity impacting waterbody/marsh	None		Minor		Major	
6	Indirect disturbance (shading, flow alterations, chemical input...)	None		Minor		Major	
		None		Minor		Major	

Riparian Zone Parameter		0	0.25	0.5	0.75	1
1	Forested buffer width	≥250'	100 – 250'	50 – 100'	25 – 50'	< 25'
2	Percent cover of riparian (top down, how much of ground surface is covered by vegetation) within 75' of water	≥75%	50 – 75%	25 – 50%	5 – 25%	< 5%
3	Evidence of loss/degradation of native riparian vegetation(linearly, how much is missing)	< 10%		10 – 50%		> 50%
4	Percent cover of invasive/non-native within 50 ft of water	None	Trace – 25%	25 – 50%	50 – 75%	> 75%
5	Presence of significant wildlife attractors	Many	Common	Some	Few	None
6	Number of layers/structure in buffer (herb, shrub, saplings, mature trees)	4	3	2	1	0

Casco Bay Fringing Marsh Field Survey Marsh ID LJ-1

Photos

123	
122	
121	

Waypoint Lists

Measurement	GPS #	Start Waypoint	Finish Waypoint	Measurement	GPS#	Start Waypoint	Finish Waypoint
Perimeter							
High/Low	1	17	28				
Invasives							

Notes:

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Casco Bay Fringing Marsh Field Survey Marsh ID LJ - 1

Perimeter w/Elevation

Perimeter GPS# 1		Perimeter GPS#		Perimeter + 40 GPS# 3		Perimeter + 40 GPS#		Other GPS#		Other GPS#	
WP #	El (ffii)	WP#	El(ffii)	WP#	El (ffii)	WP#	El (ffii)				
01	> 1504			01	> 1400						
02				02							
03	1608			03	1504						
04	1610			04	1506						
05	1610			05	1506						
06	1609			06	1505						
07	1505			07	1401						
08	1605			08	1501						
09	1605			09	1501						
10	1507			10	1403						
11	0910			11	0806						
12	1002			12	0810						
13	0905			13	0801						
14	0906			14	0802						
15	0908			15	0804						
16	0907			16	0803						
17				17							
18				18							
19				19							
20				20							

HL marsh
17-28
GPS 1

Boat-Survey Sheets

Boat Survey Date: 8/16/07 Transect/Time: 11:20 am Day 2 Page: 1

Location/Comments:

Small point

Marsh	GPS	Wpt #	Purpose/Comments
1	1	01	ph114
		02	
2		03	ph113
		04	
3		05	ph110-108, 109-103.
		06	few rock cutoffs, but mainly continuous
		07	across shore. Campground @ GPS#08. Marsh
		08	on island shore along opposite side of the
		09	channel.
		10	
4		11	ph102
		12	
5		13	ph101
		14	
6		15	
		16	
7		17	ph101-100
		18	
8		19	
		20	
9		21	ph99-97, 96
		22	
10		23	small marsh, ph95
11		24	small inlet all marsh, ph94