5-31-2007

A Comprehensive Wetland Program For Fringing Salt Marshes In The York River, Maine

Pamela A. Morgan
University of New England, pmorgan@une.edu

Jeremy Miller
Wells National Estuarine Research Reserve

Christopher Cayce Dalton
Wells National Estuarine Research Reserve

Michele Dionne
Wells National Estuarine Research Reserve

A Comprehensive Wetland Program for Fringing Salt Marshes in the York River, Maine

A Final Report Submitted to the
Environmental Protection Agency by:

Dr. Pamela Morgan[1]
Jeremy Miller[2]
Christopher Cayce Dalton[2,3]
Dr. Michele Dionne[2]

[1] University of New England
Department of Environmental Studies
11 Hills Beach Road, Biddeford ME 04009

[2] Wells National Estuarine Research Reserve
342 Laudholm Farm Road, Wells ME 04090

[3] Town of York
186 York Street, York ME 03909

May 31, 2007

Contents

Executive Summary

The overall goal of this project was to assist the Town of York, Maine, in its efforts to monitor and protect the fringing salt marshes along the York River. In particular, the project focused on potential impacts to the marshes due to shoreline development pressures. Specific objectives included (1) gathering baseline data about the marshes (2) developing a set of indicators to be used in future monitoring, and (3) generating management recommendations.

The field component of the project focused on four marsh functions: primary productivity, maintenance of animal (invertebrate) communities, provision of habitat for fish, and maintenance of plant diversity. We generated a list of candidate indicators for these functions that were relatively easy and inexpensive to measure. Six fringing salt marsh sites were then sampled along the river during summer 2005. In addition, a land use index (LUI) was calculated for the 100m buffer zone adjacent to each fringing marsh study site. This LUI analysis was also conducted for six fringing marsh sites in Casco Bay, Maine, where we had collected ecological data in the summer of 2004. We then used correlation analysis to determine if there were any relationships between the candidate indicators and the extent of upland development near the fringing salt marshes. The management component of this project focused on understanding the federal, state and local policies, laws and regulations that influenced the current management of the York River's fringing salt marshes.

While acknowledging that any list of indicators is a work in progress, we have identified several indicators of fringing marsh "health" that can be useful tools for monitoring the status of the York River's fringing salt marshes into the future. These include: aboveground biomass (live end-of-season standing crop) and stem height of *Juncus gerardii* (for primary productivity); total invertebrate density, *Mya arenaria* presence/density, and *Neanthes* sp. density (for invertebrates); *Fundulus heteroclitus* percent biomass, biomass density &/or density and *Carcinus maenas* percent biomass (for nekton); and *Spartina alterniflora* percent cover and the Evenness index (E) (for plant diversity). Based on these indicators, we then developed a monitoring plan for assessing the status the York River's fringing salt marshes in the future.

We found that the town of York has a long history of land use regulation and protection. Complementing the municipality's efforts, a number of conservation organizations are active in the community. Planning and enforcement of land use regulations, specifically shoreland and wetland ordinances, currently form the cornerstone of wetland management in York. Future efforts to protect the York River fringing marshes could be enhanced by modifications within the zoning framework, which is preventative in nature. However, actions beyond zoning should also be taken, in order to ensure that any damage or degradation to these high quality marshes, if detected in the future, can be rapidly halted and repaired.

The results of this study also contribute to our on-going efforts to understand the functions and values of the Gulf of Maine's fringing salt marshes, to communicate the value of these marshes to those who manage them, and to assist municipalities and others in their efforts to protect these unique and important habitats.

Introduction

Background

This report documents the results of a study funded by an EPA New England Wetland Program Development Grant. Scientists from the University of New England and the Wells National Estuarine Research Reserve collaborated with the town of York, Maine, to develop a Comprehensive Wetland Program for the fringing salt marshes along the York River. In particular, we focused on the impacts of increased shoreline development pressure on the health of the river's fringing marshes. In addition, the results of this study add to on-going efforts to develop indicators of salt marsh function, specifically for fringing salt marshes in New England.

Fringing salt marshes

The York River is lined by both extensive meadow marshes, which are found along the upper portion of the river, and fringing salt marshes, which line the lower section of the river. The York River's fringing marshes were the focus of this study (Figures 1-3). Fringing salt marshes in general are different from larger, meadow marshes in that they are relatively long and narrow in shape, have steeper slopes, lower elevations and soils with less organic matter than those of larger marshes. Unlike larger salt marshes, which have extensive high marsh plant communities, fringing salt marshes have more equal proportions of high and low marsh plant communities (Morgan and Short 2000).

Fringing salt marshes are especially in need of study because of their great susceptibility to environmental impacts. On their landward borders they are often abutted by residential and commercial development, and on their seaward borders they are exposed to the erosive

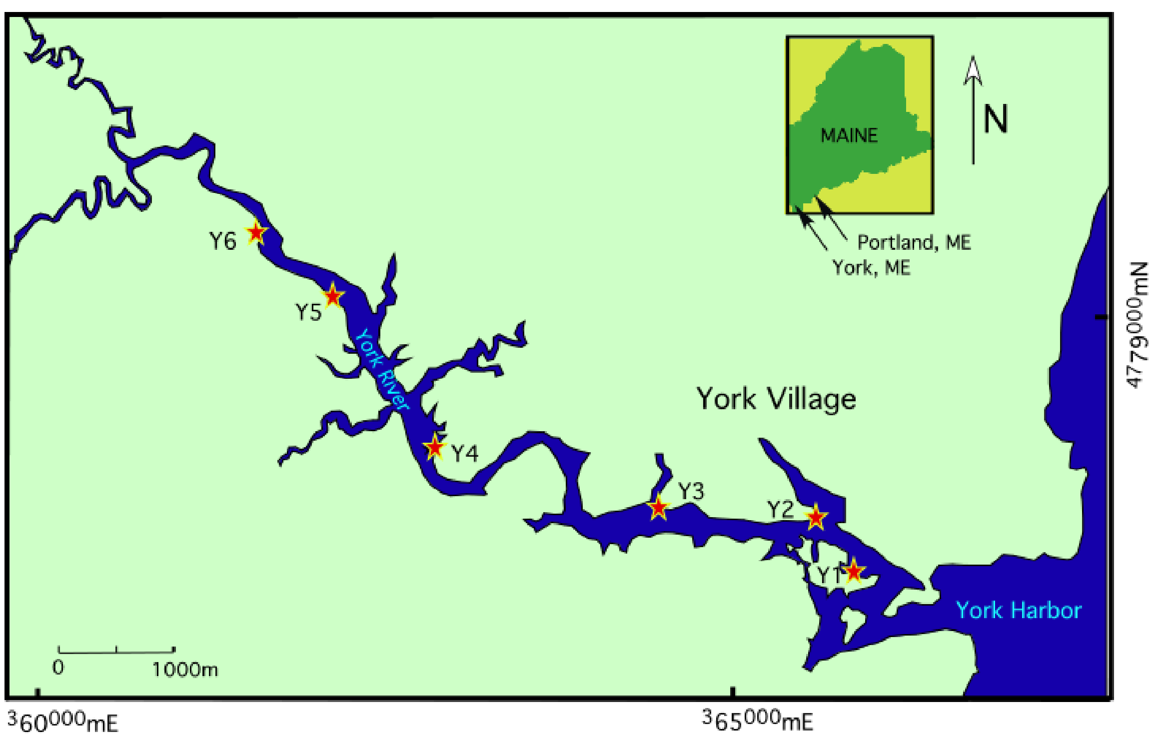


Figure 1: Location of sample sites in York, Maine.

force of waves. Because they are narrow, impacts to the borders of a fringing marsh have proportionately large effects on the entire marsh.

A Functions and Values Approach

In order to study the impacts of shoreline development on the York River's fringing salt marshes, we used a functions and values approach. That is, we identified a number of ecological functions to study that are associated with things that are "worthy, desirable or useful" to humans (Mitsch and Gosselink 1993). Specifically, we chose to study the following salt marsh functions:

- Primary productivity
- Maintenance of animal (invertebrate) communities
- Provision of habitat for fish
- Maintenance of plant diversity

The Need for Indicators of Salt Marsh Function

In addition to gathering baseline data about the four marsh functions listed above, a major part of our work was to identify useful indicators of these functions. Ecological indicators have been defined as the "measurable characteristics related to the structure, composition or functioning of ecological systems" (Young and Sanzone 2002). They can be very useful in understanding the current "health" or integrity of a particular system (a fringing salt marsh, in this case). Indicators are also important components of long term monitoring efforts, which can tell resource managers if the marshes are deteriorating, improving, or staying the same.

If effective indicators can be identified, they can help focus efforts on what is really important to measure and track over time. What are effective indicators? They are:

- Relevant to management concerns and ecological resources.
- Applicable for use in a monitoring program.
- Responsive to anthropogenic stresses.
- Interpretable and useful to environmental decision-making.

(Neckles and Kopp 2006)

In addition, we hoped to identify indicators of marsh function that were relatively easy to measure and relatively inexpensive to measure. Indicators with these characteristics would be most useful to local resource managers, such as those working to protect the fringing salt marshes in the town of York.

Connecting to Resource Management at the Local Level

In addition to this report, we have developed a long term Monitoring Plan for the fringing salt marshes of the York River. We are also developing a Fact Sheet about fringing salt marshes and their importance which will be available to state and local officials. On a local level, a well informed Town Manager, Planning Board, Planner, Code Enforcement Office (which includes environmental enforcement), and Zoning Board of Appeals helps reinforce the need for municipal-level protection for these fragile resources. Furthermore, a widespread appreciation of these marshes at the municipal level will over time reach the general public as they interact with the town to obtain building and shoreland permits. It is important that the value of these resources be widely understood since in the town of York, the body of citizens who vote form the legislative body, approving or denying funding for virtually everything that the municipality does.

On a state level, a well-informed Department of Environmental Protection, specifically in the areas of shoreland zoning and the Natural Resource Protection Act, will contribute to laws, rules and enforcement activities which have the greatest and most targeted effect. Measuring the efficacy of a state law or rule with scientific results will ideally, over time, result in laws and rules which provide the necessary protection without unnecessary bureaucracy or limitations of property rights. Some landowners whose development potential is restricted for the sake of environmental protection will raise objections. Those objections are best resolved by demonstrating a clear and worthwhile need for those restrictions.

The question of who will implement the Monitoring Plan remains open. The best approach may be to follow the framework of this project.

The York River Marshes in a Larger Context

Our study of the York River's fringing salt marshes has added to our prior work in Casco Bay, where we evaluated the functions and values of twelve fringing salt marshes over a three year period (Morgan et al. 2005a and 2005b). Data from six of these sites were combined with the York River data, which provided enough information for us to identify several useful indicators of fringing salt marsh function.

In addition, the methods we employed were modified from the Gulf of Maine Salt Marsh Monitoring Protocol, which was developed by the GPAC group to be a regional (Gulf of Maine) standardized protocol for monitoring salt marshes (Neckles and Dionne 1999). We also relied on previous work by MA-CZM (Massachusetts Coastal Zone Management) that investigated the relationship between surrounding land use and salt marsh integrity. MA-CZM continues to be involved in efforts to develop indices of biotic integrity for salt marshes in New England (Carlisle et al. 2003 and 2004). This study of the York River's fringing salt marshes therefore fits into a bigger picture, where researchers and resource managers are working together in the Gulf of Maine to better protect the Gulf's salt marshes through improved monitoring and conservation efforts.

Objectives

The specific objectives of this study were to:

1. Measure salt marsh functions of six fringing marshes along the York River.
2. Develop indicators of marsh "health" or function for fringing salt marshes that respond to increases in shoreline development.
3. Develop management enhancements for the York River's fringing salt marshes.

Figure 2: Site Y1 near the mouth of the York River.

Figure 3: Site Y4 next to I-95.

Study Sites

During the spring of 2005, we visited potential fringing salt marsh sites along the York River by boat. Six sites were then selected based on a number of criteria, including their accessibility and the extent of upland development adjacent to them. In addition, we chose sites that were closer to the mouth of the river and some farther upstream. The final six study sites are shown in Figure 1, and listed in Table 1, along with their locations (recorded with a handheld Garmin GPS).

Methods

Physical Characteristics of Fringing Salt Marsh Sites

Sampling Design

At each of the fringing marsh sites, nine quadrats were established in a stratified random manner according to the proportion of high marsh to low marsh, as described below. These nine quadrats were sample points for salinity, elevation, plant diversity, and aboveground biomass.

To determine the proportion of high to low marsh, five equally spaced transects were established across the width of each marsh, running perpendicular to the shoreline. The spans of both the high marsh and low marsh areas were then measured along each of these transects, and the total amounts of high and low marsh were calculated and compared to estimate the percent of low and high marsh at each site. These calculated percents were then used to proportionally distribute the sample points between the high and low marsh areas.

Table 1. GPS coordinates for fringing salt marsh study sites along the York River, York, Maine.

Site Number	Site Name	Start Point	End Point
Y1	Harris Island Road	N 430 07.947’, W 0700 38.854’	N 430 07.936’, W 0700 38.709’
Y2	Wiggly Bridge	N 430 08.200’, W 0700 39.015’	N 430 08.209’, W 0700 39.150’
Y3	Golf Course	N 430 08.278’, W 0700 40.044’	N 430 08277’, W 0700 39.938
Y4	Goodrich Park	N 430 08.5’, W 0700 41.503’	N 430 08.565’, W 0700 41.514’
Y5	Riverwood	N 430 09.247’, W 0700 42.111’	N 430 09.163’, W 0700 42.048’
Y6	Scotland Bridge	N 430 09.549’. W 0700 42.619’	N 430 09.9498’, W 0700 42.645’

Elevation

Elevations of the nine sample points on each site were determined using Topcon laser surveying equipment. The relative elevations of all sample points at a site were first measured by surveying from the points to a relative benchmark. These relative benchmarks were then tied into a high tide elevation on one date, which allowed for comparison of elevations between all sites. To determine the high tide line, three stakes painted with water-soluble paint were placed in each of the ten marsh sites before high tide (MHHW) on a windless day. Following high tide the water line on each stake was marked and then tied into the relative benchmark elevation at each site. The elevations of all the quadrats on all the sites were then calculated relative to 0' (mean low tide) elevation. After the elevations of the nine sample points on each marsh were determined, means and standard errors were calculated for each site.

Salinity

Soil porewater was extracted using soil sippers made of 1/4" PVC pipe inserted into the marsh to a depth of 15 cm. Holes drilled in the PVC allowed water from 10-15 cm below the soil surface to enter the sipper. The salinity of the water extracted was then determined using a standard refractometer. Samples were taken three times at each site, once each in June, July and August. Means and standard errors for the nine data points sampled at each site were calculated.

Aboveground Production of Salt Marsh Vegetation

Primary production of vascular plants at each site was evaluated by measuring the end-of-season standing crop (the live aboveground plant biomass) in early August. The end-of-season standing crop is commonly used as a metric for salt marsh primary productivity (Nixon and Oviatt 1973). Samples were collected from each marsh site at the nine stratified random points described above. All vegetation in a 0.25 m^2 quadrat at each sample point was clipped (Figure 4). Live plants were separated from dead material and all the species were separated and stems counted before samples were dried at 60°C for 48 hours and weighed. Means and standard errors for the nine data points at each site were calculated.

Figure 4: Plant biomass sampling.

Plant heights were also determined for *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii* by measuring five random shoots per sample quadrat (Figure 5). The mean heights and standard errors for each species were then calculated for each site. Stem densities were calculated for these three species as well, using a subset of the nine sample quadrats. For example, only quadrats where *S. alterniflora* was the dominant species were used to estimate its stem density value.

Figure 5: Counting plant stems.

Benthic Invertebrates

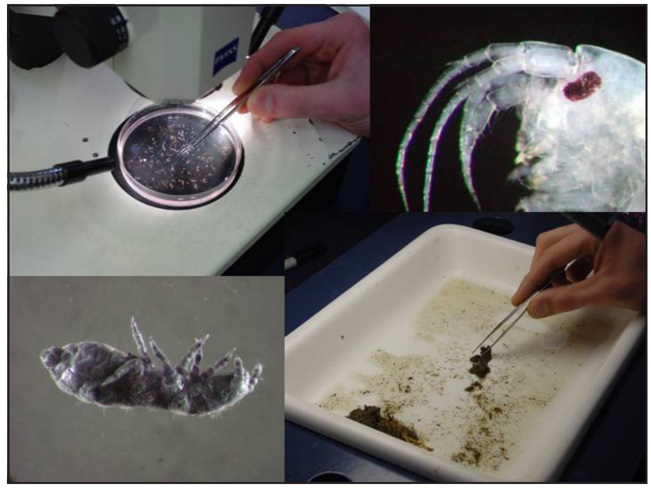


Figure 6: A photo library was created of sample specimens as they were collected and identified.

Benthic invertebrates were sampled in June in each vegetated zone of the six marsh sites (low marsh, high marsh and Phragmites, if present). Three 7.8 cm diameter cores were taken in each vegetated zone, in close proximity to the pre-established sample points (described above). The top 4 cm of substrate of each core was then collected and transported in coolers to the lab, where the samples were temporarily stored in 70% ethanol. Samples were later broken up and sifted through a 2 mm and then a 0.5 mm sieve to remove fine sediment. They were then divided into four equal parts, and two of these subsamples were analyzed. Each subsample was stained using Rose Bengal sodium salt for easier separation of invertebrates from the substrate. All invertebrates 0.5 mm or greater were removed from the substrate using forceps and transported to a 20 ml scintillation vial containing 70% ethanol. The invertebrates were then identified to the lowest possible taxonomic level using both dissecting and compound microscopy, and a variety of regional dichotomous keys (Figures 6, 7, 8).

Figure 7: Fine sediments were removed with a sieve and 2 of 4 resulting quadrats were sampled.

Figure 8: Invertebrates were identified at the compound microscope and through dissection.

A "photo-library" of our findings was compiled using Microsoft Powerpoint software and is stored at the Wells NERR for reference purposes. The mean number of individuals was calculated (mean of three sample cores) for each of the taxa identified in the marsh areas sampled, and converted to a density value (the number of individuals per square meter). These density values were then used to calculate a variety of candidate indicators.

Figure 9: Detail of a fyke net openning.

Nekton (Fish and Macro-crustaceans)

Fish utilization of vegetated marsh was measured using fyke nets (chambered trap nets) to capture fish non-destructively (as described in Dionne et al. 1999), combined with habitat mapping of the area sampled by the net. Each site was sampled during consecutive day and night spring tides on June 24, 2005 and August 18, 2005. Net openings were 1.2 m^2 opening with two 15 m long wings. The net opening was set at the lower edge of the vegetated marsh, with the wings set into the marsh at 300 to 450 from the line described by the lower edge (Figure 9). The wings were extended at an angle from the net opening into the marsh, delineating a triangle of habitat. The wing lead lines were staked to the substrate, and the wings held down to the marsh surface by modified lawn staples connected by a rope. When the incoming tide had reached its furthest extent, the tide line above the net was flagged, and the wings released by pulling the stakes out via the rope so the float lines popped to the surface, and the wings formed vertical net walls to direct fish into the center net segments (fykes) as the tide receded. Fish were collected from the cod end 2 to 4 hours later, once the tide had receded below the level of the first fyke (Figures 9 & 10). Green crabs were separated from fish immediately to minimize predation during measurement. The area of flooded marsh that drained into the net (as delineated by the wings and the marked high tide line) was cover mapped for plant species and exposed substrate. The wings were again secured to the marsh surface and sampling was repeated during the night tide.

All fish and crustaceans were counted and identified to species (except for the two shrimp species which were not always differentiated), and total biomass of each species was measured. Up to 30 individuals of each fish species were measured for total length and biomass, sampled haphazardly from a bucket with an aquarium net. For crustaceans, we measured maximum carapace width, and noted sex and color phase for the green crab. Occasionally, voucher specimens of interest were preserved. All remaining nekton were returned to the water. These methods were developed for use in an EPA-approved

Figure 10: After each of two tidal cycles, fish were collected from the cod end of the net.

monitoring program to assess the success of salt marsh mitigation as part of the expansion of the New Hampshire Port Authority in Portsmouth, NH.

Species-specific abundance, individual biomass, and total species-specific biomass were standardized by the area of marsh sampled to generate a number of density, biomass, and biodensity metrics. Biomass-densities were derived by weighting the biomass of the target taxon by the area of the habitat sampled, just as metrics for density are area-adjusted numerical abundances. Fish species were assigned to resident, transient or migratory life history strategies based on their use of marine, estuarine and freshwater habitats. Candidate indicators were those developed by Dionne et al. (2006) in a previous EPA-funded project. They were chosen for their potential to reflect the functional use of fringing marsh by the nekton (Ayvazian et al. 1992, Kneib and Wagner 1994, Tupper and Able 2000, Minello et al. 2003). Because sites were sample during the day and during the night in June and in August, mean values for candidate indicators were calculated for each site with n=4.

Plant Diversity

The species richness and relative abundance of each of the plant species growing in the marshes were assessed once at each site, in July. The point intercept method (Roman et al. 2001) was used to determine percent cover of individual species in $1m^2$ quadrats located at each of the nine stratified random sampling points (Figure 11). After quadrat sampling was complete, transects were walked down the long axis of each site and any plants that were not recoded in the quadrats were noted. The total number of plant species observed at each site was then recorded.

Data collected from sample quadrats were summarized to determine the mean percent cover for each plant species sampled on each marsh. Plant diversity indices were also calculated for the plant communities at each site. These included plant species richness (S), the Shannon Diversity Index (H') and species evenness (E). Plant relative abundance and diversity values were then used to calculate values for candidate indicators.

In addition, plants were sampled using a transect method that we modified from what is described in the GPAC Protocol (Neckles and Dionne 1999) and what has been used in previous studies by the Massachusetts Office of Coastal Zone Management (Carlisle et al. 2004). Transects were randomly located along the seaward length of each marsh. To determine the number of transects per site, we divided the length of each marsh by 20 m. Transects ran from the seaward edge of each site to the upland edge. Compass bearings of all transects were recorded. Beginning at the seaward end of each transect, the point intercept method (Roman et al. 2001) was used to determine percent cover of individual species in $1m^2$ quad-

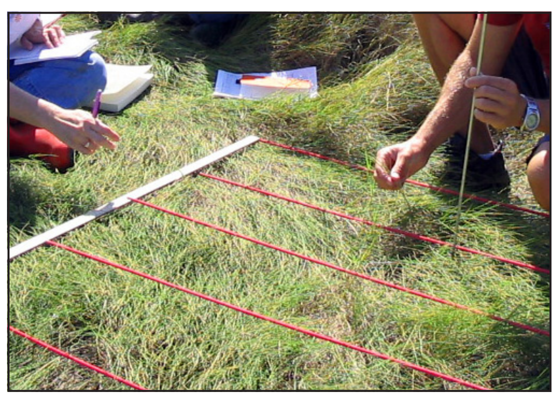


Figure 11: Determining percent cover of individual species.

rats, which were spaced 10 m apart along the transects. In addition, a quadrat was sampled at the upland edge of the marsh.

Land Use

A simple Land Use Index (LUI) was determined for each sample site. This index was adapted from an evolving methodology developed by Bruce Carlisle at Massachusetts Coastal Zone Management (MA-CZM). An application of this methodology at salt marsh sites on Cape Cod revealed a strong correlation between the LUI and several ecological metrics (including a plant index and an invertebrate index), and was found to be a reasonable predictor of biotic conditions (Carlisle et al. 2004). The LUI methodology consists of two basic elements, a remote sensing phase which uses high resolution aerial photos and GIS, and a rapid field assessment which may capture ground conditions not easily observed in aerial photos.

In the first phase, the GIS data layer "ortho_1f" consisting of georeferenced aerial photos from spring 2003 was used, courtesy of the Maine Office of GIS. The sample sites were located on the photos based on GPS data and field verification, and natural boundaries such as channels or vegetation edges were used to delineate a sample area of fringing marsh of approximately 150 to 200 meters in length. In some cases, the delineated sample site was a distinct marsh area (e.g., Y1), but in most cases the borders were somewhat arbitrary. A 100 meter buffer was drawn around each sample site.

The land uses in this buffered area were then determined and delineated using the LU21 definitions as described by the Massachusetts Geographic Information System (2002), which were the same categories used in the MA-CZM study cited above (Table 2). Residential lot sizes were estimated based on actual density of houses as shown in aerial photos. Estuarine lands (i.e., mudflats with no vegetation, as verified in the field) were deleted from the buffer and excluded from the analysis. The remaining total buffer area was calculated.

Each land use within the buffer was assigned the LUI coefficient provided by the MA-CZM methodology (Carlisle, personal communication). Coefficients range from 0 to 1, with the less detrimental land uses having higher values. For each land use, the area as measured in GIS was multiplied by the coefficient to determine an indexed area. The indexed areas were summed and divided by the total buffer area to determine the initial LUI for that sample site. Thus, a sample site surrounded by highly detrimental land uses in its 100 m buffer would have an initial LUI close to zero, while a sample site in a natural setting would have an initial LUI close to 1 (See Table 2 for LUI coefficients). For the purposes of this report, the scores from 0 to 1 have been converted linearly to a scale of 0 to 100.

A second phase of the land use analysis used a rapid assessment form to generate a secondary LUI, based on field observations (sewer or septic, evidence of tree-cutting or pesticide usage, etc). Using this worksheet, a second LUI score was obtained. We also calculated the average of the above two numbers. This methodology was also applied to six sites that we had previously studied in Casco Bay (three in the Fore River and three outside the Fore River) (Morgan et al. 2005a).

Table 2 : Land use categories and coefficient used in calculating the Land Use Index.

Land Use Type	LUI	LandUseAbr	Definition (from MA GIS website)
Cropland	0.74	CROPLAND	Intensive agriculture
Pasture	0.87	PASTURE	Extensive agriculture
Forest	0.97	FOREST	Forest
Non-forested Wetland	0.95	WETLAND	Non-forested wetland
Mining	0.96	MINING	Sand; gravel & rock
Open Land	0.98	OPEN	Abandoned agriculture; power lines; areas of no vegetation
Participation Recreation	0.75	REC PARTICIPANT	Golf; tennis; Playgrounds; skiing
Spectator Recreation	0.79	REC SPECTATOR	Stadiums; racetracks; Fairgrounds; drive-ins
Water Based Recreation	0.91	REC WATER	Beaches; marinas; Swimming pools
Residential-multi-family, 3.0 Occup	0.00	RES0	Multi-family
Residential-<1/4 Ac Lots, 3.0 Occup	0.18	RES1	lots < 1011.7 m^2
Residential-1/4 - 1/2 Ac, 3.0 Occup.	0.48	RES2	lots 1011.7 - 2023.4 m^2
Residential->1/2 Ac Lots, 3.0 Occup	0.61	RES3	lots > 2023.4 m^2
Salt Marsh	0.96	SALTMARSH	Salt marsh
Commercial	0.08	COMMERCIAL	General urban; shopping center
Industrial	0.37	INDUSTRIAL	Light & heavy industry
Urban Open	0.78	URBANOPEN	Parks; cemeteries; public & institutional greens-pace; also vacant undeveloped land
Transportation	0.20	TRANSPORTATION	Airports; docks; divided highway; freight; storage; railroads
Waste Disposal	0.75	WASTEDISPOSAL	Landfills; sewage lagoons
Water (Fresh)	0.90	FW	Freshwater
Woody Perenial	0.93	ORCHARD	Orchard; nursery; cranberry bog
Estuarine / Marine Water	n/a		Not considered; deleted from buffer area

It should be noted that the salt marsh assessment methodology used by MA-CZM has evolved considerably, and as of July 2005 used a total of 11 GIS-based parameters (of which LUI was just one, and the buffer had been expanded to 150 m), and 11 field based indicators (MA-CZM 2005 Draft).

Indicator Development

A list of candidate indicators was developed for each of the ecological parameters investigated (aboveground production, invertebrates, fish, and plant diversity) (Table 3). These lists were created based on a review of the literature as well as on the results of previous studies we had conducted in fringing salt marshes in southern coastal Maine.

Following field work during the summer of 2005, data were summarized and mean values for each candidate indicator calculated at each of the six fringing marsh study sites. For aboveground production, means were of the nine stratified random sample plots. For invertebrates, means were of the six cores sampled (three in the high marsh and three in the low

Table 3: Candidate indicators for aboveground production, invertebrates, fish, and plant diversity at York River fringing salt marshes.

<u>PLANT PRODUCTIVITY</u>

Biomass

- Live end-of-season standing crop
- Dead end-of-season standing crop

Stem density

- *Spartina alterniflora* stem density
- *Juncus gerardii* stem density
- *Spartina patens* stem density

Stem height

- *Spartina alterniflora* stem height
- *Juncus gerardii* stem height
- *Spartina patens* stem height

<u>BENTHIC INVERTEBRATES</u>

Density of individuals (no./m^2)

- Total invertebrate density
- High marsh density
- Low marsh density
- Density of *Mya arenaria*
- Density of dipterans
- Density of nematodes
- Density of amphipods
- Density of gastropods

Pollution/disturbance indicative taxa

- Percent pollution sensitive taxa
- Percent pollution tolerant taxa

Relative abundance of Polychaetes

- Percent *Capitella*
- Percent *Manayunkia*
- Percent *Fabricia*
- Percent *Pygospio elegans*
- Percent *Neanthes*
- Percent *Polydora*

<u>NEKTON</u>

Population/Biomass

- Green crab % biomass
- Shrimp % biomass
- *Fundulus* % biomass
- Tomcod % biomass
- Other fish % biomass
- Green crab density
- Green crab biomass-density
- *Fundulus* density
- *Fundulus* biomass-density
- Tomcod density
- Tomcod biomass-density
- Other fish density
- Other fish biomass-density
- Total other fish

Community/Food Web

- Number of feeding guilds

<u>PLANT DIVERSITY</u>

Relative abundance

- *Spartina alterniflora* percent cover
- *Juncus gerardii* percent cover
- *Spartina patens* percent cover
- *Phragmites australis* percent cover
- Forbs percent cover
- Salt tolerant plants percent cover

Diversity indices

- Species richness
- Shannon Weiner (H')
- Evenness (E)

marsh). For fish, means were of the four fishing events (day/night in June and day/night in August). And for plant diversity, means were of the nine stratified random sample plots.

Correlation analyses were then done comparing first the physical parameters measured at each study site (site width, site elevation, porewater salinity and distance to the mouth of the river) to the candidate indicators. This allowed us to determine if there were any significant relationships with our candidate indicators and the physical attributes at each fringing marsh study site. Following this, we calculated Pearson's correlations for all candidate indicators with Land Use Index (LUI) values for the 100 m buffer surrounding each fringing salt marsh site. Scatterplots were also generated so that we could discern if there were any patterns or relationships between the LUI values and the candidate indicators. Note that all correlation analyses included data from our previous study in Casco Bay, Maine during the summer of 2004. Six fringing marsh sites were sampled in this study, three in the Fore River and three outside the Fore River in nearby Casco Bay (Morgan et al. 2005a). These sites were included in the current analysis to give us a wider range of LUI values for comparison.

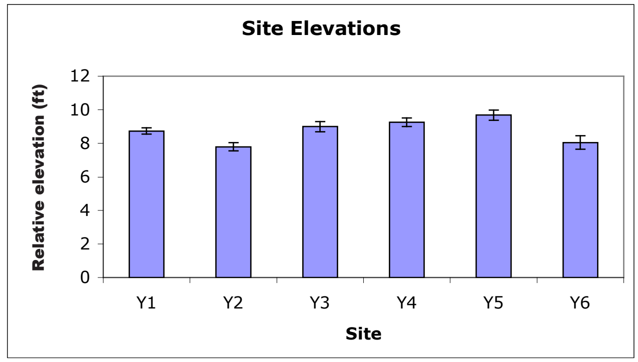


Figure 12: Mean elevations of York River fringing marsh study sites, relative to 0' tide. Values are means of nine stratified random sample points on each site. Bars are means ±1 standard error.

Results & Discussion

Field Sampling and Data Analysis

Functions and Values

In this section we summarize the results of our study of the ecological functions of the fringing salt marshes along the York River. The data we gathered about these functions during the summer of 2005 can serve as a baseline for future monitoring of the York River's fringing salt marshes.

Physical characteristics of fringing salt marsh sites

The surface elevation of the sample points at the six marshes we studied and the porewater salinity of the sites were measured in order to better understand these two important physical characteristics at our study sites. Elevation and soil salinity influence the ecology of salt marshes, especially the plant and animal communities living there.

Elevation

The mean elevation of the nine sample points for each marsh is shown in Figure 12. These elevations are not actual site elevations, but were measured relative to the 0' tide level. All sites were at elevations that supported both low and high marsh plant communities. A more complete description of the plant and invertebrate communities at these fringing marsh sites is discussed below.

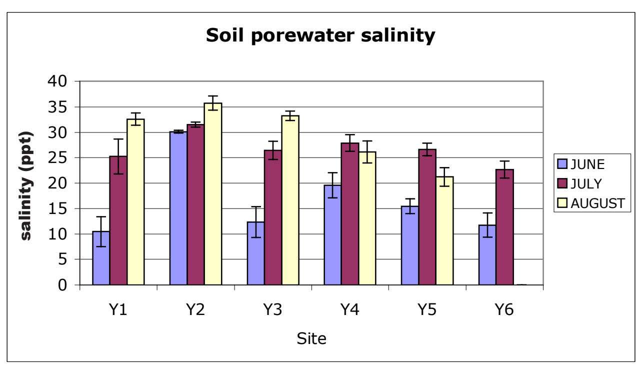


Figure 13: Average soil salinity of sites, determined from porewater extracted from York River fringing salt marsh study site's sediment in June, July and August, 2005. Bars are means ±1 standard error.

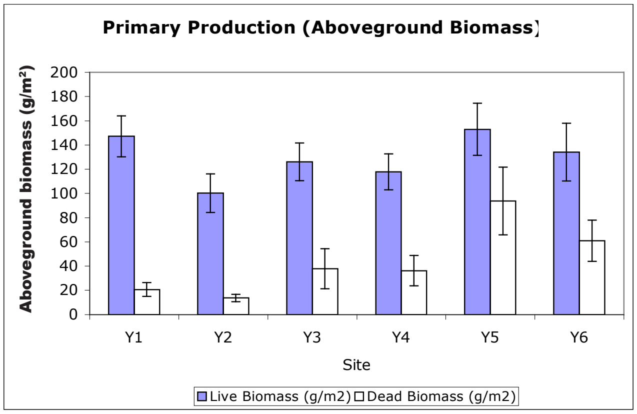


Figure 14. Aboveground biomass at York River fringing salt marsh study sites, August 2005. Bars are means of nine sample points ±1 standard error.

Salinity

The soil porewater salinities of the nine sample sites are shown in Figure 13. As expected, salinities were lower in June than in July and August. Less rainfall and decreased freshwater runoff into marshes later in the season, combined with higher rates of evaporation from the marsh surface, contribute to greater salinities later in the summer. Site Y2 had higher soil salinity values in June than did the other sites, which may affect the productivity of that site. Previous studies have found salt marsh productivity to decrease with increasing soil salinities (Linthurst 1980, Pezeshki and DeLaune 1993).

Aboveground Production of Salt Marsh Vegetation

Biomass

The end-of-season standing crop (live aboveground vegetation) is commonly employed by salt marsh ecologists to approximate the primary productivity of salt marshes in a growing season. This does not capture the belowground production, however, which can be 4-7 times greater than that of aboveground production (Marinucci 1982). In a study of coastal southern Maine/New Hampshire fringing salt marshes, Morgan and Short (2000) found that belowground production was almost five times greater than aboveground production.

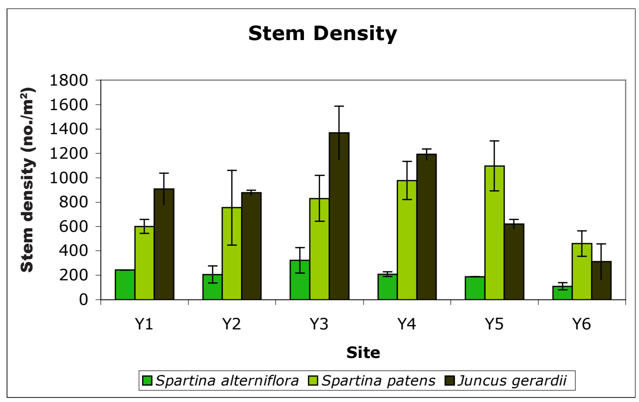


Figure 15. Stem densities at York River fringing salt marsh study sites, August 2005. Bars are means ±1 standard error.

However, measuring belowground biomass production in salt marshes is rarely done, due to the difficulty of sampling and processing belowground tissues (Gross et al. 1991).

Figure 14 shows that the mean aboveground production of the York River fringing marsh sites ranged between 100-153 g/m^2, which is similar to values we have observed in previous studies in southern Maine (Morgan et al. 2005). It should be noted that our sample method did not account for the turnover of new plant tissues during the growing season. Previous studies have shown that harvesting the peak season standing crop as a measure of aboveground production underestimates true aboveground net production by 10-15% (Nixon and Oviatt 1973).

We also measured the standing dead biomass at the end of the growing season (Figure 14). The amount of dead plant material was greater at sites farther up river, which is most likely due to the reduced tidal action experienced by sites farther from the mouth of the river.

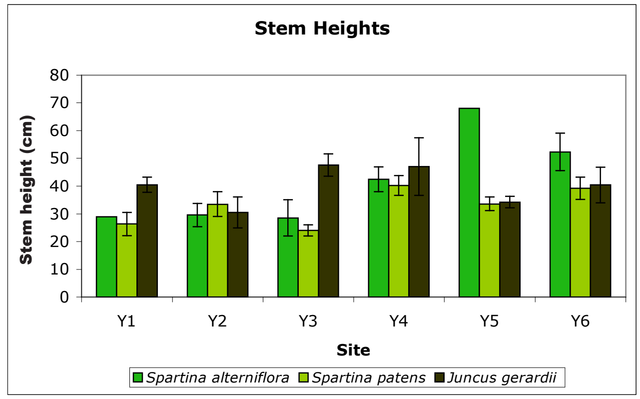


Figure 16. Stem heights at York River fringing salt marsh study sites, August 2005. Bars are means ±1 standard error.

Stem Densities of Spartina alterniflora, Spartina patens and Juncus gerardii

The mean number of *S. alterniflora* (cordgrass), *S. patens* (salt meadow hay) and *J. gerardii* (black grass) stems per square meter at the six York River fringing marsh study sites is illustrated in Figure 15. Values for cordgrass (range 110-323 stems/m^2; mean 213 stems/m^2) are similar to what we observed in a previous study in Casco Bay, where values ranged from 80-325 stems/m^2 (Morgan et al. 2005a). Stem density values for salt meadow hay were somewhat higher than what we observed in Casco Bay, where the mean density was 580 stems/m^2, compared to a range of 460-1097 stems/m^2 at sites along the York River.

Plant Heights of Spartina alterniflora, Spartina patens and Juncus gerardii

We also measured the heights of the dominant salt marsh plant species (Figure 16). Plant height may be affected by runoff from adjacent upland areas (Wigand et al. 2003), with nutrients such as nitrogen causing *Spartina alterniflora* plants to grow taller. Correlations between stem heights and the extent of shoreline development along the York River will be discussed later in the report.

Benthic Invertebrates

Invertebrates collected at the study sites were identified to the lowest taxonomic classification possible, and abundance and diversity values were calculated. Eighteen different species and numerous additional taxa of benthic intertidal invertebrates were found at the six study sites along the York River (Table 4).

The most common taxa found were annelids, specifically the polychaete worms belonging to the genus *Manayunkia* and *Fabricia*, as well as the amphipod *Chorophium insidiosum*. Of the taxa identified, a total of six were found to be pollution sensitive and four others have been described as pollution tolerant (Hiscock 2004, Weisberg et al. 1997, Wilson 1994, and Gray 1979) (Table 5). Figure 17 shows the mean densities of all organisms in the low and high marsh zones for all of the study sites. These results agree with what we have found in fringing salt marshes outside of the York River; that higher invertebrate densities occur in the low marsh zone (Morgan et al. 2005a&b).

Table 4: Invertebrate species sampled at six sample sites along the York River, June 2005.

Scientific Name	Class	Order	Zone
Alderia modesta	Gastropoda	Sacoglossa	Low
Amphipod	Malacostraca	Amphipoda	High
Amphipoda sp.	Malacostraca	N/A	Low
Anurida maritima	Insecta	Collembola	High/Low
Bivalve sp.	Bivalvia	N/A	Low
Bivalve sp.	Bivalvia	N/A	Low
Capitella capitata	Polychaeta	N/A	Low
Chironomidae sp.	Insecta	Diptera	High
Chorophium sp.	Malacostraca	Amphipoda	High/Low
Culicoides sp.	Insecta	Diptera	High/Low
Curculionidae sp.	Insecta	Coleoptera	Low
Delphacidae sp.	Insecta	Hemiptera	Low
Diapriidae sp.	Insecta	Hymenoptera	Low
Diptera pupae	Insecta	Diptera	High/Low
Dolichopodidae sp.	Insecta	Diptera	High/Low
Ephydridae sp.	Insecta	Diptera	Low
Fabricia sabella	Polychaeta	Canalipalpata (Sabellida)	High/Low
Gammarus sp.	Malacostraca	Amphipoda	Low
Gemma gemma	Bivalvia	Veneroida	Low
Hargeria rapax	Malacostraca	Tanaidacea	Low
Harpactacoid copepod	Copepoda	Harpactacoida	High/Low
Juvenile Bivalve	Bivalvia	N/A	Low
Leuctridae sp.	Insecta	Plecoptera	High
Maera danae	Malacostraca	Amphipoda	Low
Manayunkia aestuarina	Polychaeta	Canalipalpata (Sabellida)	High/Low
Manayunkia sp.	Polychaeta	Canalipalpata (Sabellida)	Low
Manayunkia speciosa	Polychaeta	Canalipalpata (Sabellida)	Low
Mercenaria mercenaria	Bivalvia	Veneroida	Low
Mite C	Acari	N/A	High/Low
Mite D	Acari	N/A	High
Mite E	Acari	N/A	High
Mite F	Acari	N/A	High
Mite G	Acari	N/A	High
Mite I	Acari	N/A	High/Low
Mya arenaria	Bivalvia	Myoida	Low
Mytilus edulis	Bivalvia	Mytilidae	Low
Neanthes diversicolor	Polychaeta	Aciculata	High/Low
Neanthes sp.	Polychaeta	Aciculata	Low
Neanthes virens	Polychaeta	Aciculata	Low
Nematoda	Nematoda	N/A	High/Low
Oligochaeta	Oligochaeta	N/A	High/Low
Orchestia grillus	Malacostraca	Amphipoda	High
Orchestia sp.	Malacostraca	Amphipoda	High/Low
Ostracoda sp.	Ostracoda	N/A	Low
Polydora sp.	Polychaeta	Canalipalpata (Spionidae)	Low
Polydora websteri	Polychaeta	Canalipalpata (Spionidae)	Low
Psychodidae sp. (pupae)	Insecta	Diptera	Low
Pygospio elegans	Polychaeta	Canalipalpata (Spionidae)	High/Low
Saldidae sp.	Insecta	Hemiptera	High
Spionidae sp.	Polychaeta	Canalipalpata (Spionidae)	High/Low
Streblospio benedicti	Polychaeta	Canalipalpata	Low
Tabaninae sp. (larva)	Insecta	Diptera	High/Low

However, the York River fringing marshes are different from marshes we have studied in Casco Bay and along the Fore River in that the densities of invertebrates found in the York River marshes were greater. The greater density of invertebrates in York River marshes may be a result of less impact along the York River's shoreline. Although the density of organisms appears to vary from site to site, abundance values alone may not be a good in-

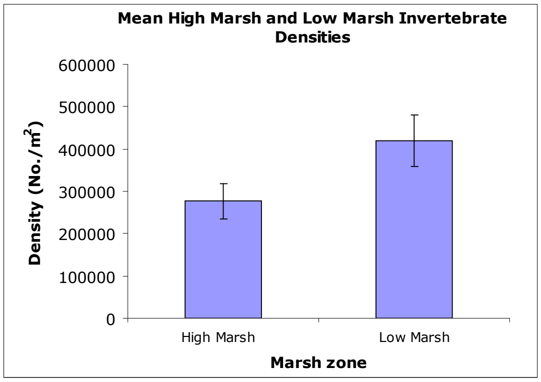


Figure 17. Mean high marsh and low marsh densities for all invertebrates, York River study, June 2005. Bars are means of six marshes ±1 standard error.

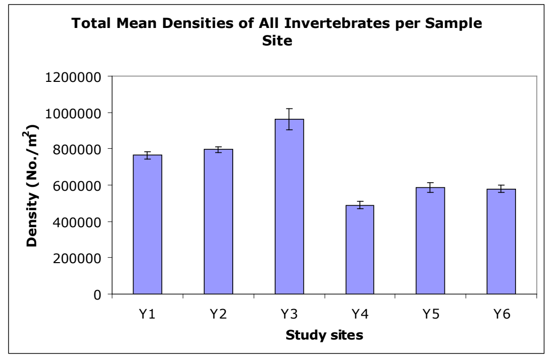


Figure 18. Total densities of all invertebrates per site, York River study, June 2005. Bars are means ±1 standard error.

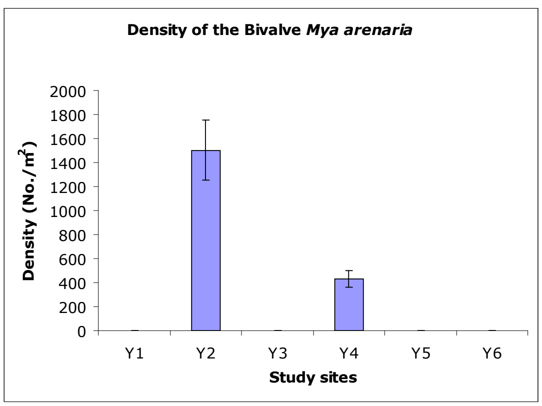


Figure 19. Density of the bivalve Mya arenaria at each study site, York River, June 2005. Bars are means ±1 standard error.

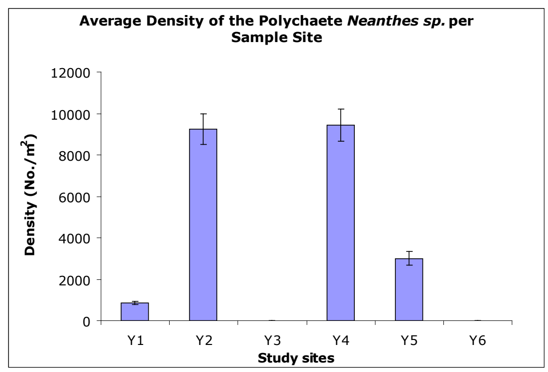


Figure 20. Density of the polychaete Neanthes sp. at each study site, York River, June 2005. Bars are means ±1 standard error.

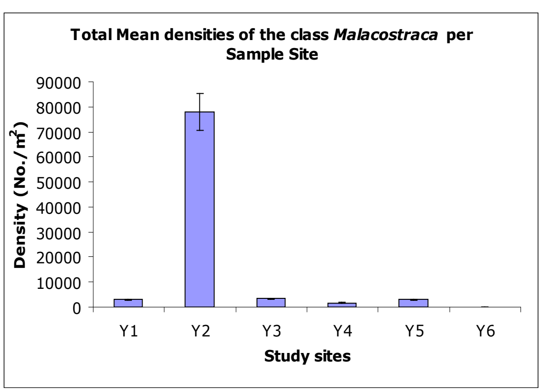


Figure 21. Density of organisms in the class Malacostraca at each study site, York River, June 2005. Bars are means ±1 standard error.

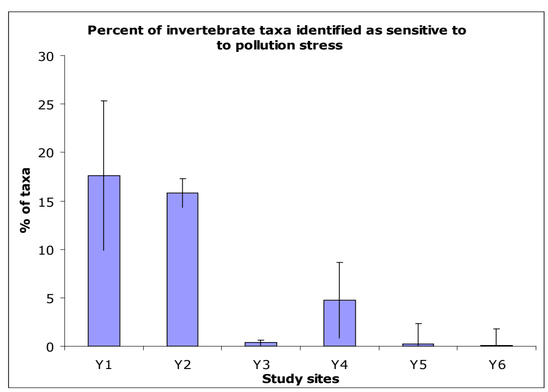


Figure 22. Percent of organisms identified as sensitive to pollution stress, York River study sites, June 2005. Bars are means ±1 standard error.

Table 5: Species identified as either pollution tolerant, sensitive, or successional by previous studies (Hiscock, et al. 2004, Weisberg, S.B. 1997, Wilson, J.G. 1994, and Gray, J.S. 1979).

Pollution Sensitive	Pollution Tolerant	Successional
Mya arenaria	*Capitella sp.*	*Neanthes sp.*
Gammarus sp.	*Streblospio benedicti*	*Polydora sp.*
Pygospio elegans	*Polydora sp.*	*Ostracoda sp.*
Fabricia sp.	*Chorophium sp.*	
Hargaria rapax		

dicator of marsh health and function. Instead, the presence or absence of certain pollution indicative species, or measures of species diversity, may be better indicators Gray (1979).

Two species of interest (*Mya arenaria* and *Neanthes* sp., Figure 23 & 24) were found in high numbers at two of the York River study sites (Y2 and Y4), while *Mya arenaria* was completely absent from any of the other sites, and *Neanthes* were found sporadically at a few sites in low numbers (Figures 19 & 20). We had previously identified *Mya arenaria*, the soft shelled clam, as susceptible to pollution-induced changes in fringing salt marshes, as we did not find them at any of our sample sites along the Fore River, and at only one reference site in Casco Bay, where anthropogenic impacts to the marshes were minimal (Morgan et al. 2005a).

In addition, along the York River we found high numbers of organisms in the class Malacostraca at site Y2 only. They were sparse or completely absent at other sites (Figure 21). These organisms are known to be negatively impacted by pollution inputs to a system (Hiscock 2004, Cabioch et al. 1980). Along the Fore River, we saw very few of these organisms (Morgan et al. 2005a).

Sites Y2 and Y4 are both adjacent to town parks, so runoff from the adjacent uplands is likely to be relatively pollution-free. This was reflected in the invertebrate communities of these two sites, as they contained a large percentage of pollution sensitive species (Figure 22).

Figure 23: The clamworm, Neanthes sp.

Figure 24: The softshell clam, Mya arenaria.

Table 6. Nekton species sampled by fyke nets at six York River fringing salt marsh sites in 2005.

	Site Y1		Site Y2		Site Y3		Site Y4		Site Y5		Site Y6	
FISH	June	Aug	June	Aug	June	Aug	June	Aug	June	Aug	June	Aug
American Eel (*Anguilla rostrata*)		X						X			X	
Atlantic Herring (*Clupea harengus*)				X				X		X		
Mummichog (*Fundulus heteroclitus*)								X		X	X	X
Northern Pipefish (*Syngnathus fuscus*)									X			
Pollock (*Pollachius virens*)	X											
Red Hake (*Urophycis chuss*)							X					
Silverside (*Menidia menidia*)	X	X		X					X	X		X
Tomcod (*Microgadus tomcod*)	X											
Winter Flounder (*Pseudopleuronectes americanus*)						X						
CRUSTACEANS												
Bent Opossum Shrimp (*Praunus flexuosis*)	X											
Green Crab (*Carcinus maenas*)	X	X	X	X	X	X	X	X	X	X	X	X
Sand Shrimp (*Crangon sp.*)	X	X		X					X			

Nekton (Fish and Macrocrustaceans)

Species Caught, Life Histories and Feeding Guilds

Nine finfish species and three macrocrustacean species were collected from our fringing marsh study sites (Table 6). The green crab (*Carcinus maenas*) was the only species caught at every fishing event. Common estuarine resident fish such as mummichogs (*Fundulus heteroclitus*) and Atlantic silverside (*Menidia menidia*) were present at many sites, along with less common species such as red hake (*Urophycischus chuss*), pollock (*Pollachius virens*), and Atlantic herring (*Clupea harengus*). The latter are considered marine transient species, meaning that they spawn in marine waters, and then feed in estuaries as juveniles and/or adults. Table 7 lists all of the species caught by family, along with the life history attributes and feeding guild to which each species of fish belongs. Note that benthivores, planktivores, omnivores and piscivores all use the fringing salt marshes along the York River.

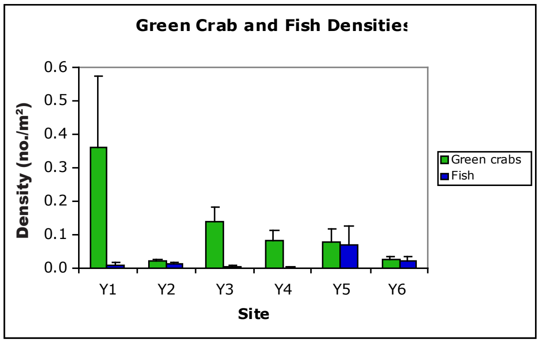
Table 7. Nekton species captured in fyke nets at York River fringing salt marsh sites. Modified from Dionne et al. (2006). The species are organized by family. Life history attributes are based on a classification developed by McHugh (Ayvazian et al. 1992). Catadromous fish spawn in salt water then migrate to freshwater to mature, whereas anadromous species follow the reverse pattern. Marine transients are fish that spawn in marine waters, and feed in estuaries. Estuarine residents remain in/near estuaries throughout their life cycle. Estuarine spawners reproduce and spend their early juvenile stages in estuaries, but then return to marine waters to mature. The tomcod presents a unique life history pattern, as it migrates from the estuary to freshwater to spawn, then returns to the estuary.

Finfish		**Life History**	**Feeding Guild**
ANGUILLIDAE	FRESHWATER EELS		
Anguilla rostrata	American eel	resident-catadromous	piscivore
CLUPEIDAE	HERRINGS		
Clupea harengus	Atlantic herring	marine transient	planktivore
GADIDAE	CODFISHES		
Microgadus tomcod	Atlantic tomcod	resident-anadromous	piscivore
Urophycis chuss	Red hake	marine transient	piscivore
Pollachius virens	Pollock	marine transient	piscivore
CYPRINODONTIDAE	KILLIFISHES		
Fundulus heteroclitus	Common mummichog	estuarine resident	omnivore
ATHERINIDAE	SILVERSIDES		
Menidia menidia	Atlantic silverside	estuarine resident	planktivore
PLEURONECTIDAE	RIGHTEYE FLOUNDERS		
Pleuronectes americanus	Winter flounder	estuarine spawner	benthivore
SYNGNATHIDAE	PIPEFISHES		
Syngnathus fucus	Northern pipefish	estuarine resident	planktivore

Crustaceans			
CRANGONIDAE			
Crangon septemspinosa	Sand shrimp	estuarine resident	
PORTUNIDAE			
Carcinus maenas	Green crab	estuarine resident	
PALAEMONIDAE			
Praunus flexuosus	Bent opossum shrimp	estuarine resident	

Densities of Individuals and Biomass Densities

Whether we look at the number of individuals per unit area or the biomass density, it is clear that green crabs (*Carcinus maenas*) outnumber and outweigh all of the fish combined that are using the York River fringing salt marshes (Figure 25). In fact, green crabs made up 69-97% of all of the biomass sampled at the sites. The situation in the York River is not unique – we found similar densities of green crabs and fish in fringing salt marshes along Casco Bay and the Fore River (Morgan et al. 2005a&b, Morgan et al. 2005a). Green crabs are not native to Maine, and there is very little known about their impact on the fish that use New England salt marshes.



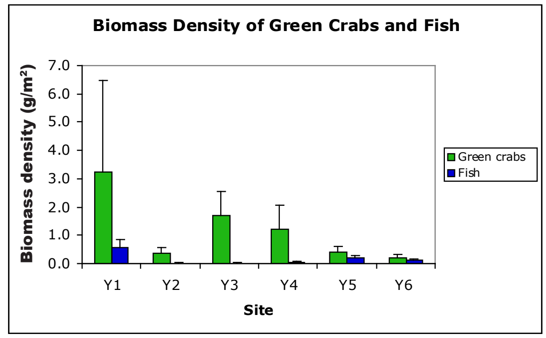


Figure 25. Green crab and fish (a) densities and (b) biomass densities at York River fringing salt marsh study sites, August 2005. Bars are means ±1 standard error.

It should be noted that because fish were sampled only two times (June and August) and in only one year, our results may not be representative of the fish communities using these sites. Natural variability in the highly mobile category of nekton is difficult to account for without long-term sampling. To gain a more complete picture of the presence and role of nekton in these marshes, more sampling is needed. However, the kinds and amounts of fish that we caught in the York River during our June and August 2005 fishing events are similar to what we observed in Casco Bay fringing salt marshes in 2002-2004.

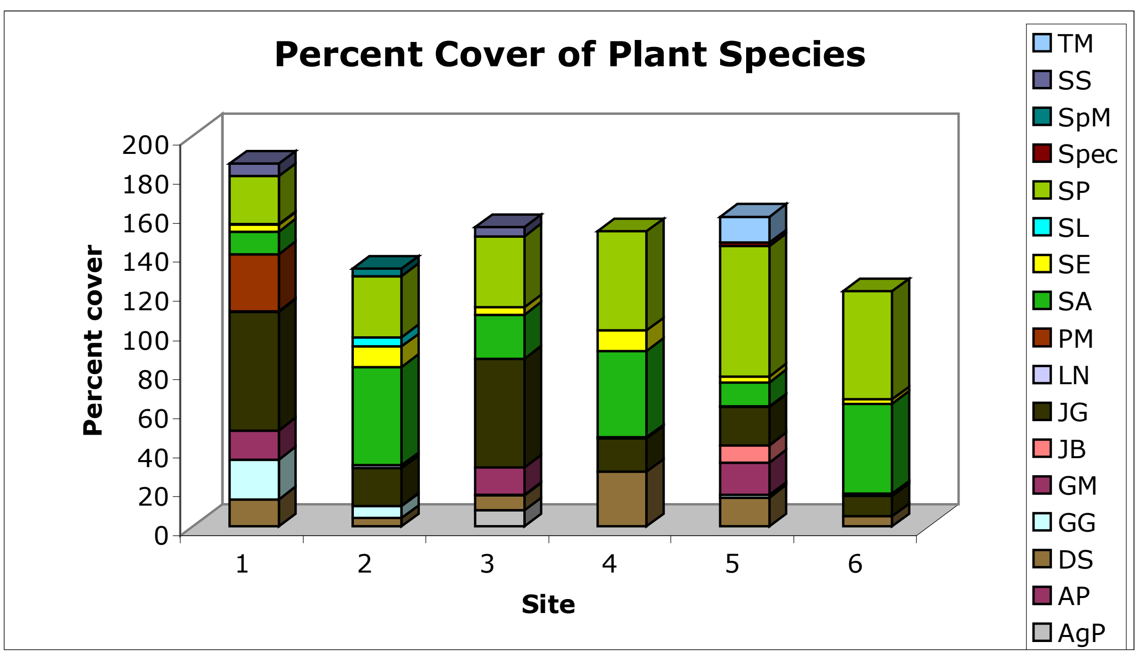


Figure 26. Plant species percent covers at six York River fringing salt marsh sites. Values are means of nine sample quadrats per site. AgP = Agropyron pungens, AP = Atriplex patula, DS = Distichlis spicata, GG = Puccinellia maritima, GM = Glaux maritima, JB = Juncus balticus, JG = Juncus gerardii, LN = Limonium nashii, PM = Plantago maritima, SA = Spartina alterniflora, SE = Salicornia europeae, SL = Sueda linearis, SP = Spartina patens, Spec = Spartina pectinata, SpM = Spergularia marina, SS = Solidago sempervirens, TM = Triglochin maritimum.

Table 8. Plant diversity values for six fringing marsh sites along the York River. H', S, E values were determined from nine sample quadrats per marsh site. "Forbs" represents the total percent cover of all broad-leaved plants (not grasses, sedges and rushes).

Site	H'	E	S	*Spartina alterniflora* (%)	*Spartina patens* (%)	*Juncus gerardii* (%)	***Distichlis spicata*** **(%)**	Forbs (%)
Y1	0.844	0.811	11	11.6	24.7	60.7	13.8	54.7
Y2	0.749	0.749	10	50.4	31.1	19.3	4.2	16.9
Y3	0.752	0.752	10	22.2	36.4	55.8	7.6	22.7
Y4	0.645	0.829	6	44.4	50.9	17.1	28	10.7
Y5	0.797	0.765	11	12.2	66.4	19.6	14.7	33.3
Y6	0.599	0.709	7	46.2	55.1	10.4	5.1	3.3

The data we have collected here can serve as a benchmark for future monitoring of the fish communities using the York River fringing marshes. A more complete account of the nekton data collected for this study can be found in the Appendix.

Plant Diversity

Fringing salt marshes, like all salt marshes, can be divided into two areas, a high marsh zone and a low marsh zone. The low marsh, which is flooded twice each day, is dominated by the species *Spartina alterniflora*. The high marsh, which is flooded only on high spring tides, is more diverse, with *Spartina patens* (salt meadow hay) and *Juncus gerardii* (black grass) being two common species there. The mean percent cover of plant species observed in the nine sample quadrats at each of the six study sites is illustrated in Figure 26. Actual percent cover values are included in the Appendix. All six York River fringing salt marshes had both high and low marsh zones, although the proportion of high to low marsh varied from site to site. Site Y4, for example, was predominantly high marsh, with a small strip of low marsh, as indicated by the low percent cover of *Spartina alterniflora*. Overall, the plant species composition of the York River fringing marshes was similar to what we have observed in other fringing salt marshes along the southern Maine/New Hampshire coast (Morgan et al. 2005a&b, Morgan and Short 2000).

Sampling marsh vegetation using the transect method resulted in a larger species list per site, largely due to the deliberate placement of a sample quadrat at the upland edge of the marsh along each transect. Sampling with nine stratified random quadrats captured 18 plant species, whereas sampling with the transect method captured 30 species (complete species lists and percent covers are included in the Appendix). Plants such as bittersweet (*Celastrus orbiculatus*), morning glory (*Ipomeae* sp.), rugosa rose (*Rosa rugosa*), and poison nightshade (*Solanum tuberosum*) were all observed at the transition zone between marsh and upland. In addition, some species known to grow only where soil salinity levels are lower were observed only along the upper reaches of the marsh using the transect method. These were salt marsh sedge (*Carex palaceae*) and salt marsh bulrush (*Scirpus robustus* and *Scirpus robustus*). However the dominant salt marsh plants were sampled by both methods. Therefore, if capturing the species that live along the upland edge of the marsh is an important study objective, sample quadrats must be included in this area. If this is not important, then sampling using fewer randomly located quadrats will save time and will give you a good overall representation of the marsh site. Random sampling is also important if you want to calculate diversity indices, as discussed below.

Table 8 shows several measures of plant diversity, including the Shannon-Weiner Index (H'), species richness (S), and evenness (E) for each of the sites studied. The diversity indices were calculated using data from the nine stratified random quadrats, not the transect data. This is because to calculate these indices, one must use data generated from a random sample (Zar 1996). Both the number of species and the evenness of the distribution of species determine the Shannon-Weiner Index. Hence, a high diversity value (H') is obtained by a more even distribution of species and a greater number of species. Species richness (S) is the total number of different species observed in the sample quadrats at each site. Evenness (E) is the ratio of observed diversity to maximum diversity, $E = H'/H_{max} = H'/\ln S$ (Magurran 1988). Values for E describe how close the set of species abundances for a marsh site is to having maximum diversity, where the relative abundances for all species would be equal.

As can be seen in Table 8, fringing marsh site Y4 was most floristically diverse, followed by site Y1. Overall, the York River fringing marshes are more diverse than those we studied in Casco Bay, where the average Evenness value (n=9) was 0.608, and the range was 0.311 to 0.834 (Morgan et al. 2005a).

Land Use

Initially, project staff followed the Massachusetts CZM method by doing both GIS analysis and a field questionnaire (rapid assessment). The method called for taking the average of these two scores. Including prior sample sites in Casco Bay and the Fore River, the GIS analysis score ranged from a minimum of 20.3 to a maximum of 97.4. The rapid assessment scores were much less variable, ranging from 73.1 to 96.3, with 12 sites falling between 75 and 85. Since the most pronounced effect of using the average of the two components was to greatly dampen the range of Land use Index values, it was decided to drop the rapid assessment results and just use the GIS analysis results, illustrated in Figures 27-30.

Indicator Development

As discussed above, to identify the best indicators of fringing salt marsh "health" as it relates to the extent of development along the shoreline, we first composed lists of candidate indicators for each of the marsh functions of interest, including aboveground production, invertebrates, nekton, and plant diversity. After collecting field data during the summer of 2005, we compared these candidate indicators to the

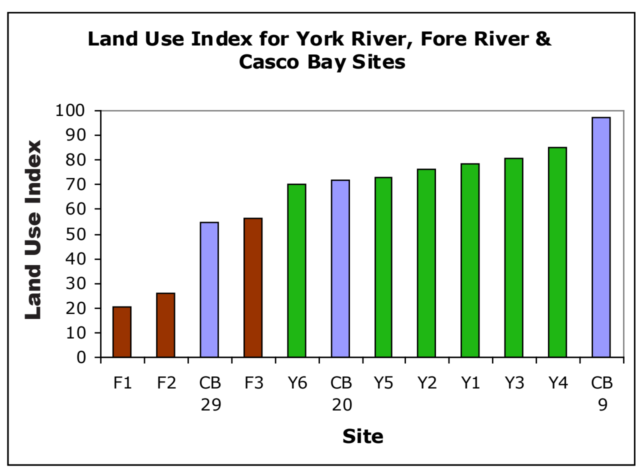
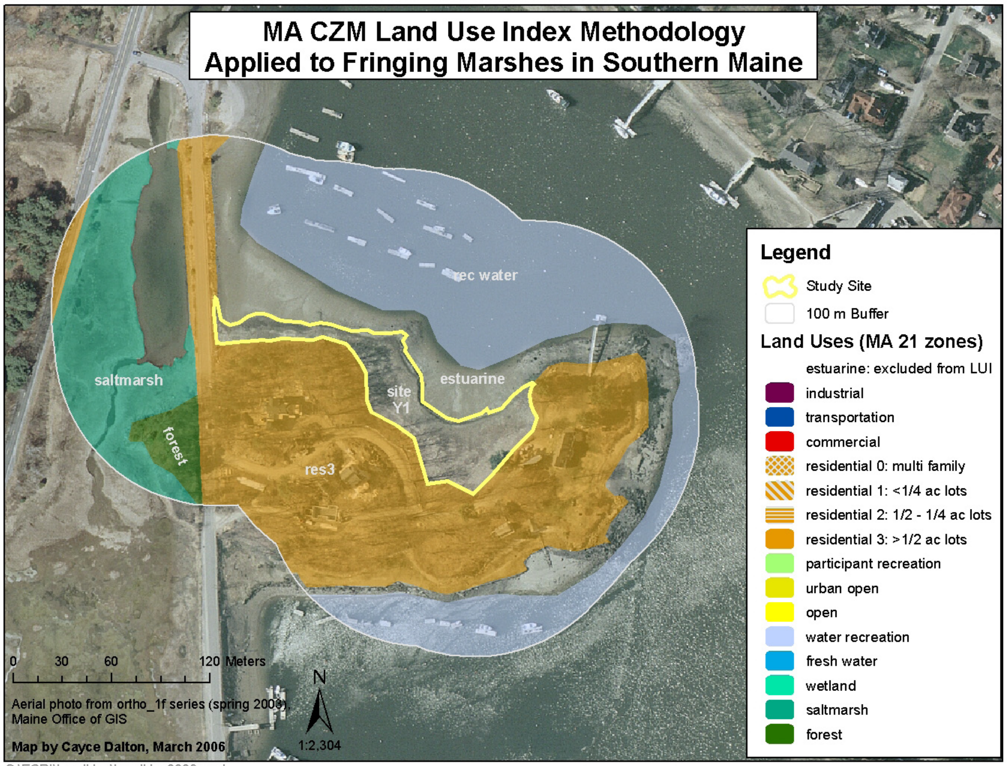
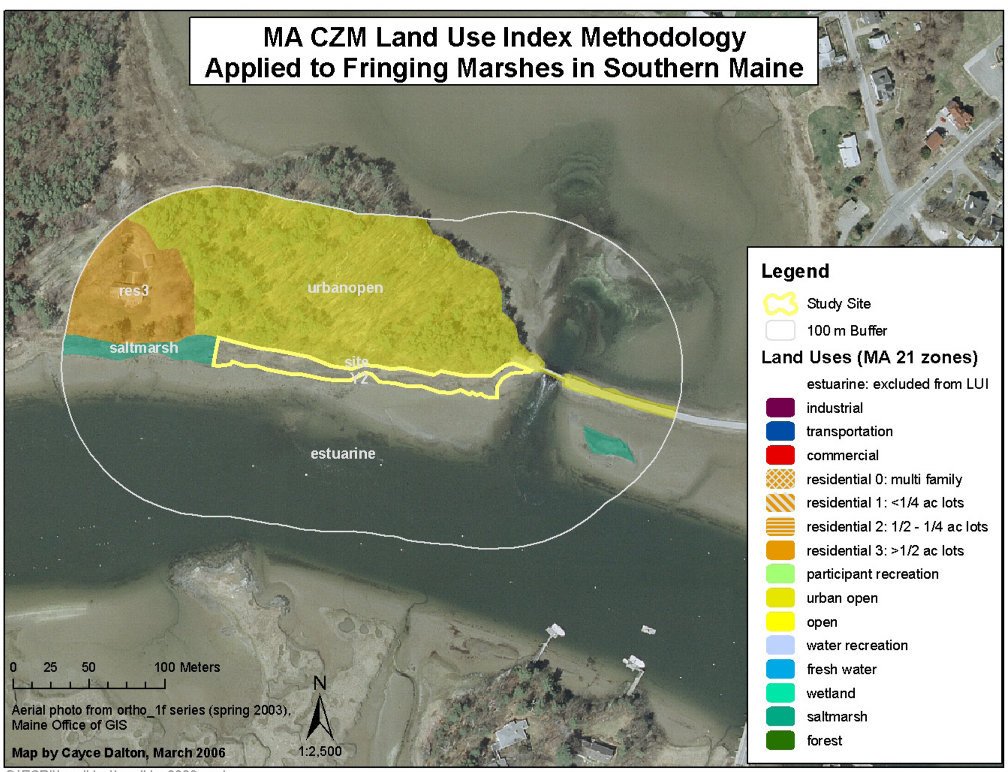


Figure 27. Land Use Index values for six fringing salt marsh study sites along the York River and Casco Bay. Values are calculated from a GIS analysis of a 100 m buffer around each sample site.

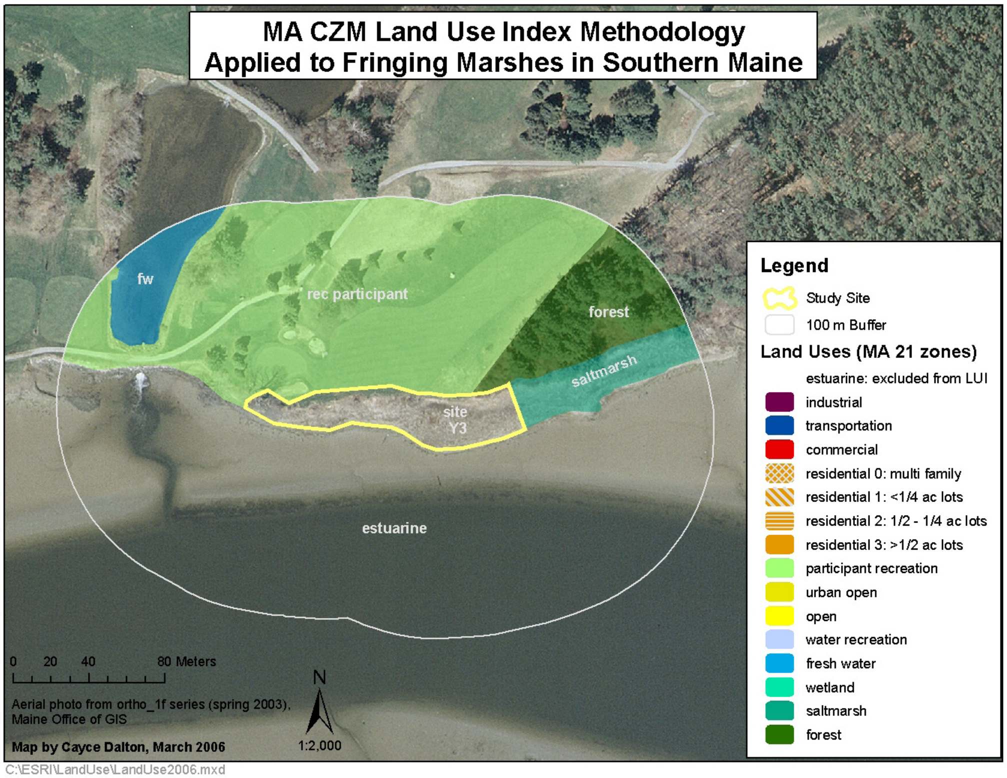


C:\ESRI\LandUse\LandUse2006.mxd



C:\ESRI\LandUse\LandUse2006.mxd

Figure 28. Land Use Index maps for Y1 and Y2. Marshes studied are outlined in yellow. Land uses were delineated for this project in GIS. Aerial photos used in the analysis were taken in spring 2003.



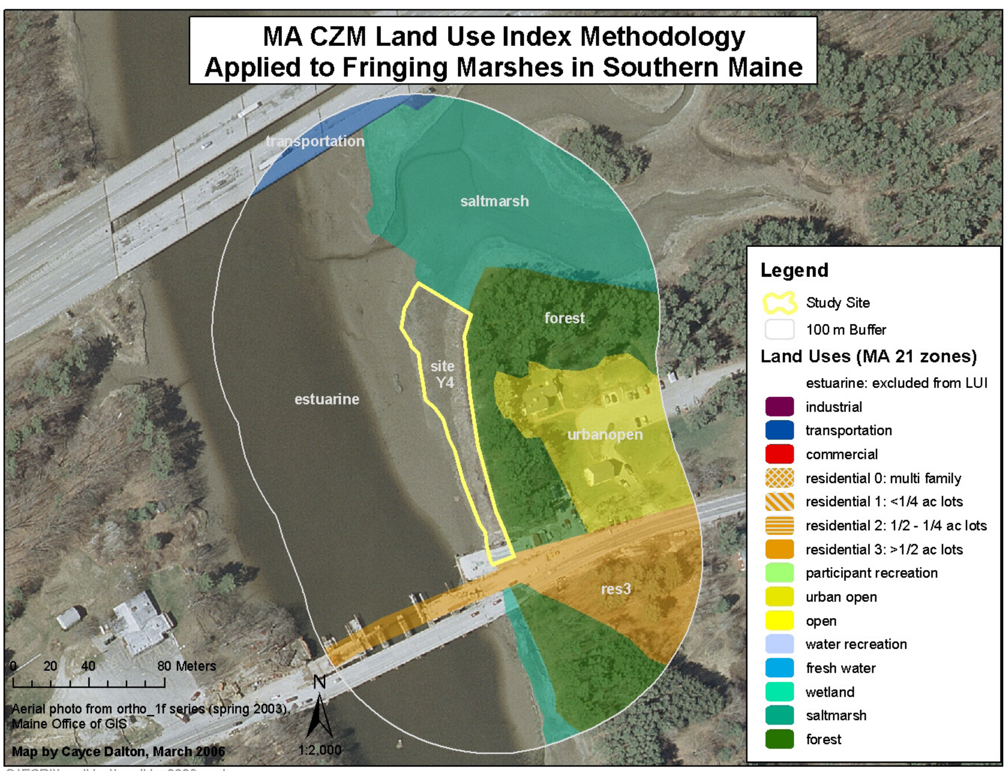
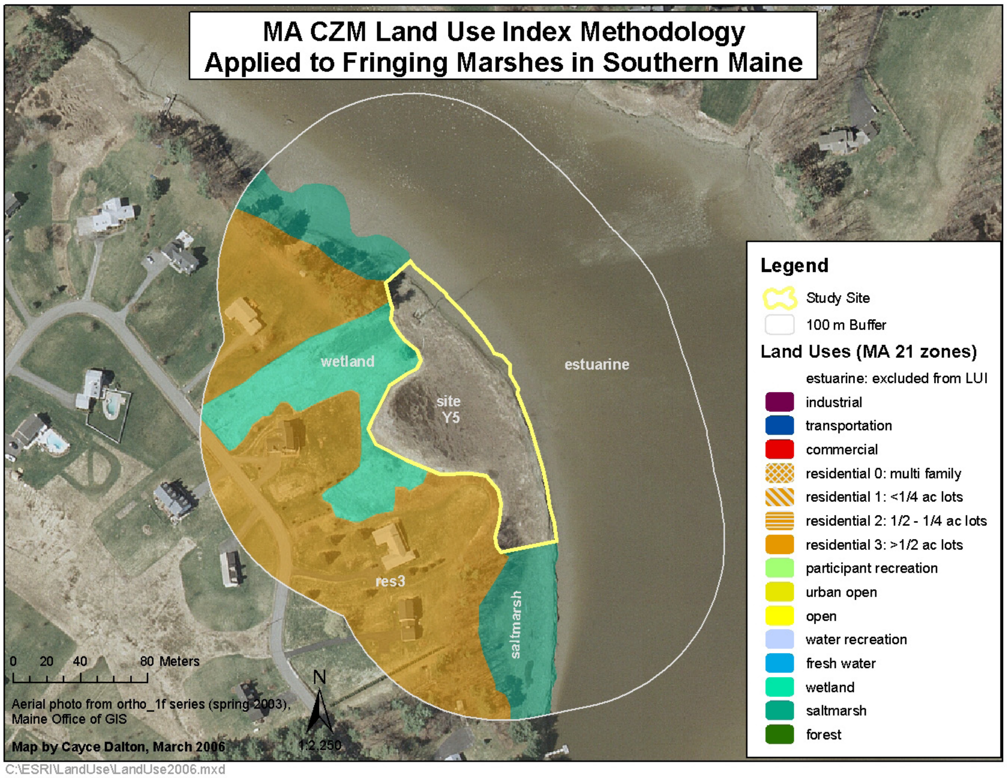


Figure 29. Land Use Index maps for Y3 and Y4. Marshes studied are outlined in yellow. Land uses were delineated for this project in GIS. Aerial photos used in the analysis were taken in spring 2003.



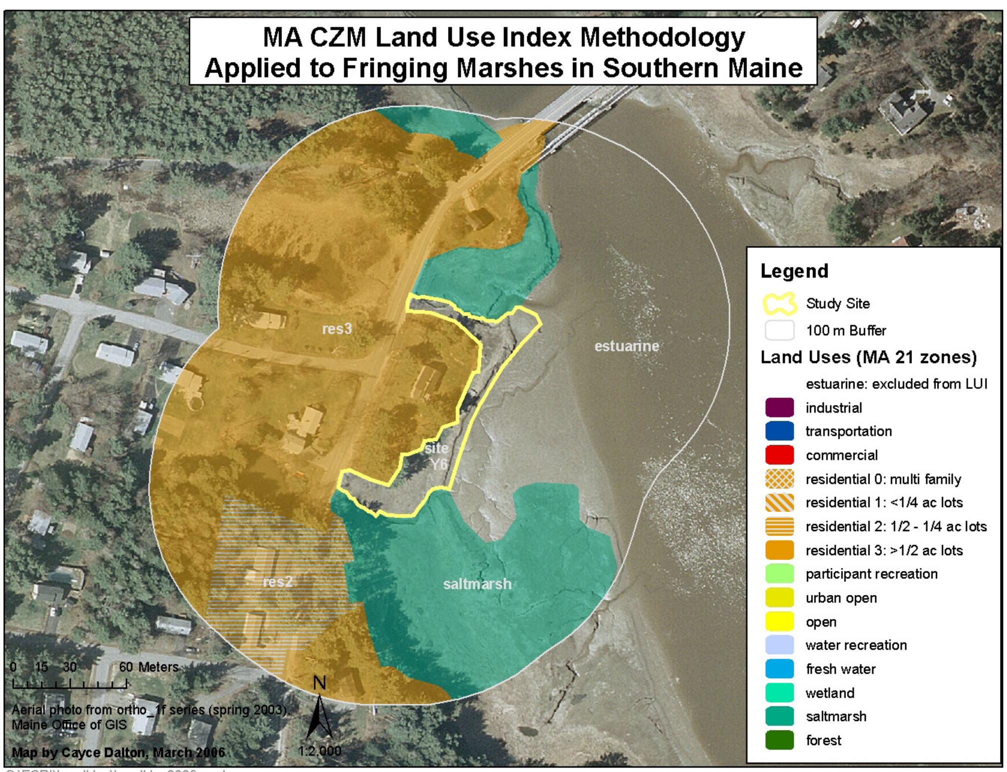


Figure 30. Land Use Index maps for Y5 and Y6. Marshes studied are outlined in yellow. Land uses were delineated for this project in GIS. Aerial photos used in the analysis were taken in spring 2003.

Land Use Index values calculated for each study site. To broaden the range of LUI values we could use for the correlation analysis, we also included data from six additional fringing salt marshes located in Casco Bay and along the Fore River. The results presented below are therefore based on data from twelve fringing marsh sites, unless otherwise noted.

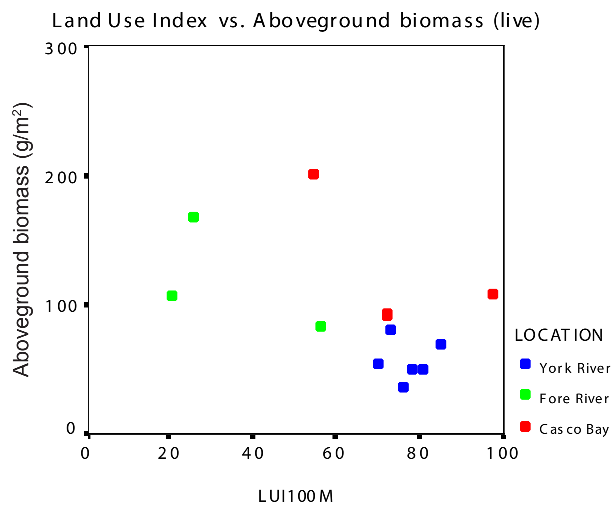


Figure 31. Correlation of Land Use Index values with aboveground biomass values for twelve fringing salt marsh sites in southern Maine (r= -0.539, NS). York River sites are indicated by the blue squares.

Aboveground Production of Salt Marsh Vegetation

Although none of our candidate indicators for aboveground production were significantly correlated with adjacent land use as measured by the Land Use Index, several did demonstrate strong relationships with the LUI. The end-of-season standing crop was greater at sites adjacent to more highly developed uplands (r= –0.539) (Figure 31). This could be attributed to runoff from developed uplands, which often includes nitrogen (Bertness et at. 2002, Wigand et al. 2001). Nitrogen is known to be a limiting nutrient in salt marshes; therefore the addition of nitrogen stimulates plant growth (Morris 1982). The stem height of *Spartina alterniflora* (cordgrass) was also greater at sites adjacent to more highly developed uplands along the York River (r= –0.519) (Figure 32a). Again, this could be an effect of nutrient input to the marshes from the adjacent uplands. Wigand et al. (2003) observed the same relationship in fringing salt marshes in Narragansett Bay. However, cordgrass stem height also correlated with soil porewater salinity (r= –0.581) and marsh width (r= +0.722).

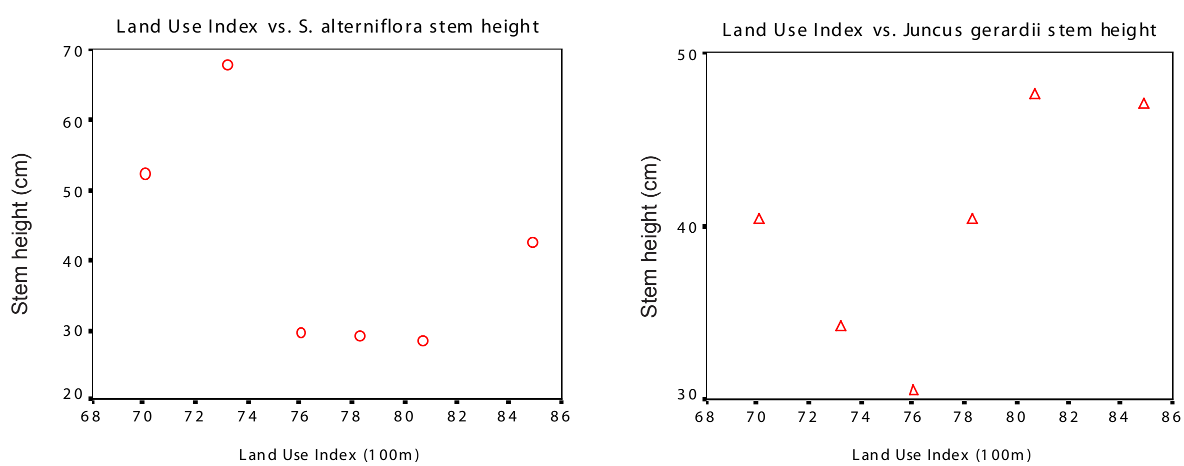


Figure 32. Correlation of Land Use Index values with (a) Spartina alterniflora and (b) Juncus gerardii stem heights for six fringing salt marsh sites along the York River (Pearson correlation coefficients (a) -0.519, NS and (b) 0.623, NS).

In addition, the stem heights of black grass (*Juncus gerardii*) were observed to be shorter in salt marshes adjacent to more developed uplands (r= 0.623) (Figure 32b). Bertness and others (Donnelly and Bertness 2001, Bertness et al. 2002, Wigand et al. 2001, Wigand et al. 2003) have observed that in salt marshes under stress, *Spartina alterniflora* migrates landward, outcompeting typical high marsh species, such as *Juncus gerardii* (black grass) and *Spartina patens* (salt meadow hay). They attribute this to a combination of factors, including rising sea level and increased shoreline development with its associated nitrogen runoff. Correlation results are also included in the Appendix.

Benthic Invertebrates

Anthropogenic disturbances that occur in coastal areas can impinge on habitats and communities of conservation interest, such as important bird feeding grounds or juvenile fish habitat, of which benthic invertebrates are an important component (Ferns et al. 2000; Minello 1999). Because managers are often required to assess the outcome of permitting various intrusive activities on benthic communities (Dernie et al. 2002), a method for rapidly assessing benthic community structure should prove valuable to the permitting/management process. Relationships between land use, levels of nutrients and contaminants, and the condition of the biotic communities of receiving waters are well studied for fresh water ecosystems (Allan and Flecker 1993), but few studies have addressed these relationships in estuarine ecosystems (Comeleo et al. 1996; Valiela et al. 1997).

In this study, we attempted to identify possible indicators in salt marsh benthic invertebrate communities of anthropogenic stress due to shoreline development along the York River. Although we were able to sample for invertebrates only once during the summer 2005 season, we were able to identify several indicators that warrant further investigation.

Although there were no significant correlations between the calculated Land Use Index (LUI 100m) and our invertebrate candidate indicators, there were some strong relationships as well as some presence/absence situations that show strong potential for use as indicators of anthropogenic disturbance. An important step in developing indicators of marsh health is to determine whether changes in communities are indeed from anthropogenic effects or from natural physical variables. To address this we ran correlations between our invertebrate candidate indicators and several physical characteristics at the sites in an attempt to weed out any false positive results. Correlation results are also included in the Appendix.

Total densities of invertebrates showed a possible relationship with LUI (r=0.526) (Figure 33). This fig-

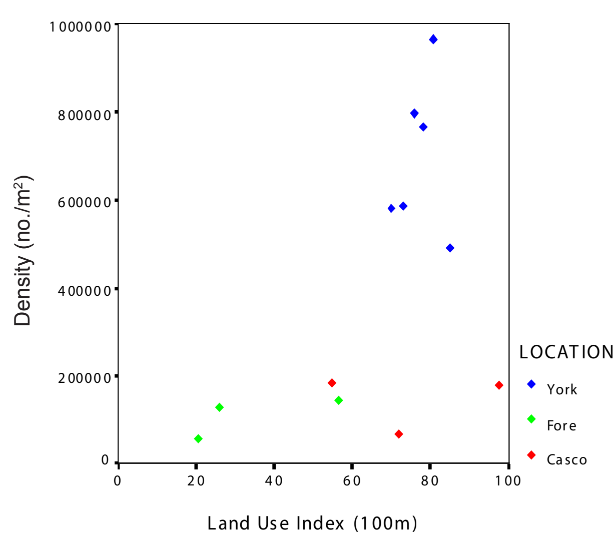


Figure 33: Correlation between total invertebrate densities and LUI (100m).

ure shows that when shoreline development is greater, the abundance of organisms at a site is less. However, confounding this is the fact that numbers of pollution tolerant and opportunistic species will initially increase after a disturbance to a habitat. When marine communities are affected by pollution, species richness often decreases, while the abundance of a few tolerant species increases (Word et al. 1990).

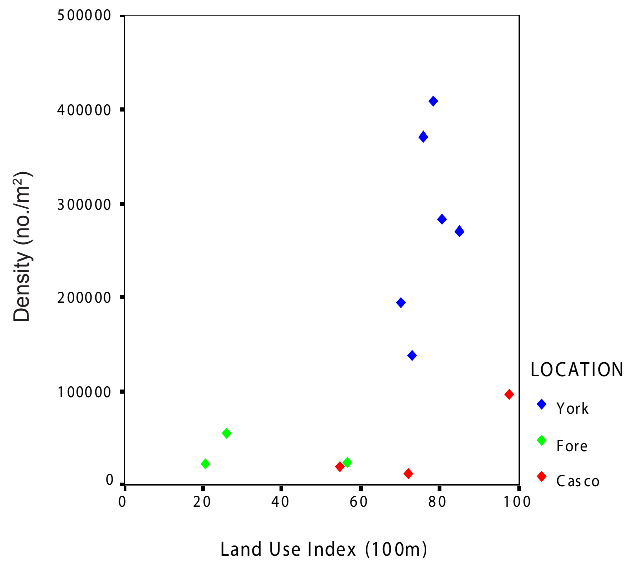


Figure 34: Correlation between high marsh densities and LUI (100m) .

Another possible relationship exists between the density of invertebrates in the high marsh and LUI (r=0.534). Again, when development adjacent to the salt marsh is greater, the total abundance of organisms in the high marsh is less (Figure 34). Any runoff or pollution from the adjacent uplands will enter the high marsh zone first, so this may be the cause of the decrease in the abundance of invertebrates with increasing development.

Although *Mya arenaria* densities did not correlate significantly with LUI scores, the presence/absence of this bivalve may alone be enough to indicate a possible pollution problem (Figure 19 – see above). *Mya* was found only at sites Y2 and Y4, which had little to no development in adjacent upland areas. In fact, the upland adjacent to site Y4 had the highest LUI score among the six York River study sites. The presence of *Mya arenaria* in a sample may be a very good indication of marsh health and function, as *Mya* numbers have been shown to decrease in the presence of pollutants (Hiscock et al. 2004). Densities of the polychaete *Neanthes* sp. followed the same trends as those of *Mya arenaria* in the York River. This species has been identified by other studies as a successional species and relatively intolerant of pollution, however it will move in and out-compete pollution tolerant species such as *Capitella* sp. and *Spionidae* (Pocklington and Wells 1992). Both Y2 and Y4 were completely absent of *Capitella*, and had minimal numbers of *Spionidae* present, which could be a sign that these sites may be in some phase of succession or rebound from a disturbance.

Nekton (Fish and Macrocrustaceans)

Nekton have been identified as a good group of organisms to use in developing indices of salt marsh integrity or health because they (1) span the full range of trophic levels in a marsh, (2) contain a sufficient diversity of species, and (3) respond to both short term and long term changes in habitat (Dionne et al. 2006). The fish communities of estuarine waters have been observed to respond to anthropogenic stress in a variety of ways, including changes in species abundances and biomass, as well as in the structure of the community as described by fish life histories and feeding types (Hughes et al. 2002).

As explained above, the list of candidate indicators we used was modified from a list developed for another EPA-funded study (Dionne et al. 2006). After summarizing the data and running correlation analyses between candidate indicators and Land Use Index values, several indicators appear to reflect the state of the upland adjacent to our fringing marsh sample sites. Green crab percent biomass, along with several *Fundulus* indicators, correlated well with LUI values. This was true if we considered only the six York River sites, as well as if we included the six Fore River/Casco Bay sites in the correlation analysis. Values presented here were calculated using all twelve fringing marsh sites.

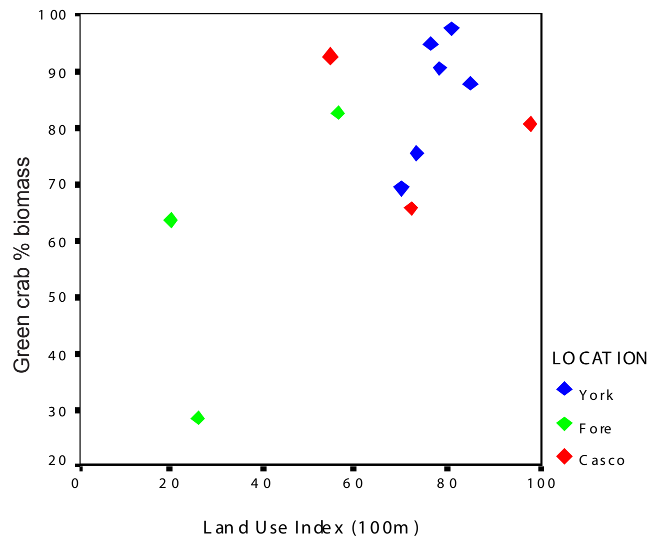


Figure 35. Correlation of Land Use Index values with green crab percent biomass for twelve fringing salt marsh sites in southern Maine (r= +0.653, p=0.05). York River sites are indicated by the blue squares.

The percent of total fish and macrocrustacean biomass comprised of green crabs (GC%B) was greater in marshes adjacent to less developed shorelines (r= +0.653, p=0.05) (Figure 35). It is important to note that for sites along the York River, GC%B also correlated with how far the sites were from the mouth of the York River. Sites farther from the mouth of the river had a lower percentage of green crabs (r= –0.868, p=0.05).

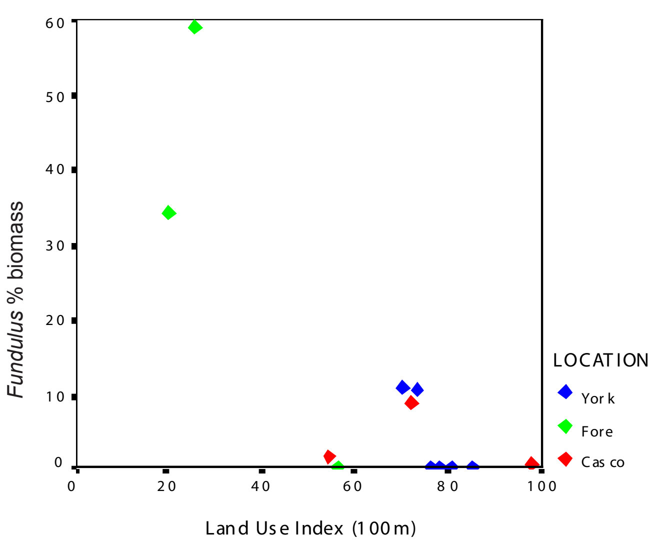


Figure 36. Correlation of Land Use Index values with Fundulus percent biomass for twelve fringing salt marsh sites in southern Maine (r= -0.812, p=0.01). York River sites are indicated by the blue squares.

The presence of *Fundulus heteroclitus*, the common mummichog, may also be an important indicator of fringing marsh health and associated impacts due to adjacent development (Figure 36). *Fundulus* percent biomass (r=–0.812, p=0.01), *Fundulus* density (r=–0.773, p=0.01) and *Fundulus* biomass density (r=–0.817, p=0.01) all showed highly significant correlations with Land Use Index values for fringing marsh sites. In sites adjacent to more highly developed shorelines, *Fundulus* was not as abundant. It is difficult, however, to determine if the decrease in *Fundulus* is due to impacts from upland development or to impacts from the green crab. Sites with a greater proportion of green crabs had fewer *Fundulus* (r= –0.922, p=0.01).

Dionne et al. (2006) also found that green crab abundance was lower in salt marsh sites adjacent to more highly developed shoreline areas. In addition, they identified several other candidate indicators that could prove useful in developing an index of tidal wetlands health using fish. Although our results did not show similar patterns, our sampling was quite limited, and so further studies will be needed to refine the list of indicators for fish and crustaceans.

Plant Diversity

As with the other marsh functions of interest, to narrow down our list of plant diversity candidate indicators, we looked for correlations between these candidate indicators and the Land Use Index values for twelve fringing marshes (six York River sites and six Casco Bay/Fore River sites). The candidate indicators that correlated best with Land Use Index values were the percent cover of cordgrass (*Spartina alterniflora*) and two diversity indices, H' (Shannon Weiner Index) and E (Evenness Index) (Figures 37-39). The percent cover of *Spartina alterniflora* was greater at sites adjacent to more heavily impacted uplands. This relationship was highly significant (r= –0.714, p=0.01). As explained above, Bertness et al. (2002) observed that marshes adjacent to more highly developed uplands had a greater proportion of low marsh, which is dominated by *Spartina alterniflora*. This predominance of cordgrass was attributed to increased shoreline development and the associated increase in nitrogen inputs to marshes that results from this development. It should be noted that the York River sites, the percent cover of cordgrass was also greater at sites with a lower mean elevation, which is expected. This species grows almost exclusively in the low marsh zone, which occurs at lower elevations.

Both diversity indices (H' and E) correlated well with LUI values. Our results show that the more developed the adjacent upland, the less diverse the plant community. This relationship was highly significant, both for H' (r= 0.779, p=0.01) and for E (r= 0.926, p=0.01). None of the physical variables we measured correlated with either of these indices, making either of them a good choice for our final indicators list.

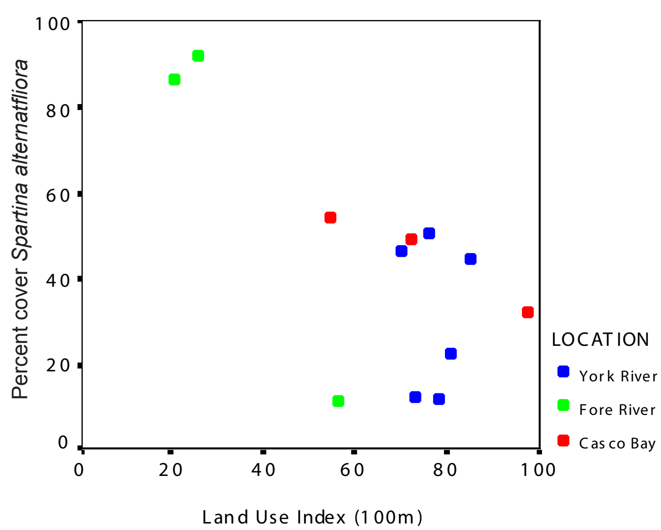


Figure 37. Correlation of Land Use Index values with percent cover Spartina alterniflora for twelve fringing salt marsh sites in southern Maine (r= –0.714, p=0.01). York River sites are indicated by the blue squares.

Summary

One of the primary objectives of this study was to identify indicators of fringing salt marsh "health" that are responsive to increases in shoreline development. Our research has led

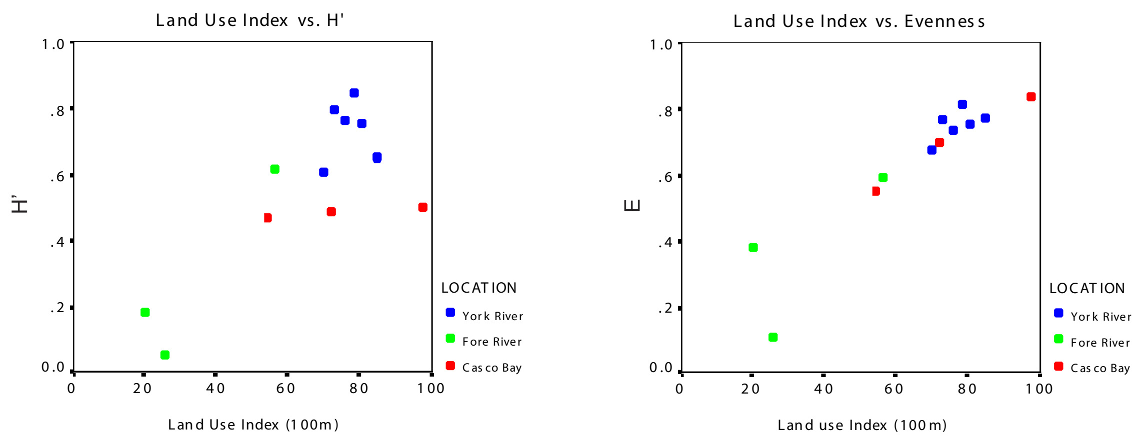


Figure 38. Correlation of Land Use Index values with (a) Shannon Weiner Index (H') and (b) Evenness Index (E) for twelve fringing salt marsh sites in southern Maine (R= (a) 0.779, p=0.01; (b) 0.926, p=0.01). York River sites are indicated by the blue squares.

us to conclude that there are several indicators that have the potential to be useful tools for monitoring the status of the York River's fringing salt marshes into the future. We also realize that the indicators we have identified need further testing and refinement. We must also acknowledge that any list of indicators is a work in progress, as new threats to fring-

Table 9. Indicators of fringing salt marsh "health" that are responsive to increases in shoreline development. This list was generated from data collected at York River fringing salt marsh study sites (during summer 2005) and Casco Bay fringing salt marsh study sites (during summer 2004).

Functions assessed	**Associated values**	**Indicators**
Primary productivity	Provides underlying support for estuarine & offshore food webs.	• Aboveground biomass (Live end-of-season standing crop) • Stem height of *Juncus gerardii* (black grass)
Maintenance of animal (invertebrate) communities	Supports shellfish & finfish production for recreational & commercial use; Supports estuarine & offshore food webs.	• Total invertebrate density (for entire marsh and/or for high marsh only) • *Mya arenaria* (softshelled clam) presence/density • *Neanthes* sp. density
Provision of habitat for fish	Provides nurseries for young fish, including many commercially important species, Supports finfish populations for estuarine & offshore food webs.	• *Fundulus heteroclitus* (common mummichog) percent biomass, biomass density &/or density • *Carcinus maenas* (green crab) percent biomass
Maintenance of plant diversity	Provides habitat for animal species, Provides unique biodiversity / aesthetic value	• *Spartina alterniflora* (cordgrass) percent cover • Evenness index (E)

ing marshes will arise in the future. Having said that, the list of indicators we developed should capture the effects of shoreline development on four important marsh functions and their associated values (Table 9). This list of indicators is an important component of the Monitoring Plan we developed for the town of York's fringing salt marshes (see Appendix).

Management Discussion and Analysis

An overview of federal, state and local laws, rules and regulations was conducted, with special emphasis on the municipal level. Original source material included state and federal laws and regulations, the Town of York Comprehensive Plan and Zoning Ordinance, and meetings with the Town Planner and GIS Department. In the later part of the project, one of the authors began working full-time for the town of York in environmental enforcement position, greatly augmenting project staff knowledge of municipal wetlands policy.

Federal Laws, Regulations and Designations

Introduction

There is a large body of federal legislation, regulation, executive orders, memoranda of agreement, guidance and other documents which together create the federal management framework that ultimately applies to York River wetlands. Touching briefly on some of the major ones, the Rivers and Harbors Act of 1899 prohibits alteration of any navigable river, as well as laying out other protections to the nation's waters. The language of the Act is quite restrictive, although it is rarely used for environmental protection and will not be covered in detail here. Basic national policy guidance and appropriations on the environment are provided by the National Environmental Policy Act (NEPA) of 1970. NEPA requires federal agencies to review the environmental effects of their actions, requiring in many cases an Environmental Impact Assessment. The Federal Agriculture Improvement and Reform Act of 1996 (Farm Bill) deals with conservation of wetlands on agricultural lands. The Transportation Equity Act for the 21st Century (TEA-21) also deals with environmental protection through funding to restore wetlands, purchase conservation or scenic easements, address sprawl and other transportation-related issues. The North American Wetlands Conservation Act of 1989 provides funding and administration for the implementation of the North American Waterfowl Management Plan. All of these laws have actual or potential effects on York River wetland management, although for the purposes of this report they are considered part of a constellation of laws that form a backdrop to town-level management. Detailed review of this large and detailed body of federal documents is beyond the scope of this project.

Clean Water Act

The Clean Water Act is widely and actively in use for the management of wetlands across the country. Under the Clean Water Act (CWA), the Environmental Protection Agency (EPA) and the US Army Corps of Engineers (USACE) work together to manage and protect the nation's surface waters, which are defined to include adjacent wetlands. Summarizing greatly, this extensive body of legislation creates designated uses for each waterbody, sets water quality standards for those uses, and when monitoring indicates the standards are not being met, there are a series of implementation strategies for achieving attainment.

Although formally this Act is based on water quality monitoring, most surface waters in the country are not directly monitored or are only partially monitored, meaning statistical inference and uncertainty play a large role in implementing the CWA.

The science of setting water quality standards is the domain of the EPA. The agency has published *Water Quality Standards for Wetlands* and *Wetlands Non-point Source Guidance*, two documents which present guidelines for an extensive list of water quality contaminants relating to designated uses. It is up to the states and tribes to adopt standards which provide an equal level of protection to these standards, but they may be different. These state/tribe standards must be EPA-approved.

The CWA regulates point sources through Section 402 which created the National Pollutant Discharge Elimination System (NPDES) regulatory program. The Maine Department of Environmental Protection has assumed NPDES administration in the state. The CWA prohibits filling of wetlands (or more precisely, depositing fill or dredged materials in to the nation's waters as defined by EPA, and that definition includes wetlands) through section 404. The USACE handles permitting and enforcement under section 404, and develops related policy. The EPA participates by reviewing permit applications, and has veto power. An advisory role is played by the US Fish and Wildlife Service and the National Marine Fisheries Service. Three recent NPDES permits have been approved in the town of York, but none in the York River.

The CWA does not authorize the EPA to regulate non-point source pollution, instead relying on a grants program (section 319) that supports state or local development and implementation of non-point source management plans. This program has evolved so that its current focus is on supporting best management practices when part of a holistic watershed plan or Total Maximum Daily Load (TMDL) in that area. The state is required to submit an Integrated Water Quality Monitoring and Assessment Report (305b) to the EPA every two years which lists all impaired waters in the state. The York River does not appear on the latest available copy of this report (2004) as having impaired estuarine/marine waters, so currently no TMDL is contemplated for the York River.

Another potential resource provided for by the CWA is the Clean Water State Revolving Fund (CWSRF), which has been used to implement non-point source projects (under section 319) and management plans developed under a National Estuary Program (NEP). CWSRF grants require state matching funds of 20%. Although the York River is not currently in an NEP, it has benefited from a section 319 watershed study through the Wells NERR.

Coastal Zone Management Act

The U.S. Coastal Zone Management Act of 1972 (16 USC 1451-1464, Chapter 33; P.L. 92-583, October 27, 1972; 86 Stat. 1280) has the primary aim to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone." It established a voluntary program called the National Coastal Zone Management Program which called for coastal states to establish management plans for their coastal regions. Such plans were subject to federal approval, after which federal grants were available to implement the plans. This law has been amended several times to bolster national consistency;

insert performance evaluations, public access and energy self-sufficiency provisions; and make numerous budget modifications. In 1985, the Act was amended to create a second program, the National Estuarine Research Reserve Program. The primary implications of this Act for the town of York's coastal wetlands are felt through the Maine Coastal Program and potentially through federal budget changes which may expand or contract, depending on available resources in the state.

Rachel Carson National Wildlife Refuge

One purpose of the National Wildlife Refuges is to provide vital habitat for waterfowl and other migratory birds. The US Fish and Wildlife Service also has a goal of protecting "trust species," such as certain anadromous fish. Currently, only a small portion of coastal land near Brave Boat Harbor (not part of the York River) is designated as part of the Rachel Carson NWR. However, this NWR has expressed interest in acquiring additional lands near the upper reaches of the York River.

US Fish and Wildlife Service Gulf of Maine Coastal Program

Under the US Department of Interior, the USFWS operates the Gulf of Maine Coastal Program. This program focuses on protecting habitat for migratory birds, sea-run fish and federally threatened and endangered species, and takes a non-regulatory, cooperative approach to working with other agencies and private organizations and individuals. Over the past decade, about $32 million in federal funding has been directed toward Maine conservation projects, leveraging five times that amount in non-federal matching funds. This represents a potential future source of assistance in York River management.

North American Wetland Conservation Act

This Act encourages partnerships among federal agencies and other organizations to manage and conserve wetlands, with a focus on migratory birds, fish and wildlife. The Act authorizes about $15 million in funding for projects in the US. These funds are available specifically for public/private partnerships, and can be used to purchase land or water rights for the protection and enhancement of wetlands if it furthers the goals of the North American Waterfowl Management Plan.

The Act has had a direct impact on the York River intertidal marshes, because the York Land Trust—in concert with the USFWS Gulf of Maine Coastal Program, Mt. Agamenticus to the Sea Coalition, Maine Department of Inland Fisheries and Wildlife, Rachel Carson NWR, and Maine Wetlands Protection Coalition—was awarded a $1 million grant in October 2005 to acquire for conservation over 200 acres of salt marsh and upland buffer in the York River. Over 700 acres were provided by participating groups as non-federal match for this grant.

Maine State Laws, Regulations and Designations

State regulations, rules and programs which are relevant to the York River coastal wetlands are also extensive, and many of them are cross-referenced between different levels and organizations within government. The Maine Revised Statutes Annotated (MRSA), contains many sections regarding coastal wetlands. These sections typically make statements acknowledging the value of the resource, define essential terms, and set statewide legislative goals, but do not contain specific management guidance. Many detailed regulations are also contained within MRSA, but often the rulemaking authority is delegated to a state agency such as the Department of Environmental Protection, Department of Marine Resources or State Planning Office. In other instances, such as with comprehensive plans and zoning codes, individual municipalities are required enact their own rules according to statewide guidelines. Below is a review of the state-level legislation and programs which relate to York River coastal wetlands.

Maine Coastal Program

The Maine Coastal Program is the key to state-level management of coastal natural resources. This program was created in 1978 in response to the Federal Coastal Zone Management Act of 1972 (see above). Its objectives (38 MRSA §1801) are established by the State of Maine as:

1. Port and harbor development. Promote the maintenance, development and revitalization of the State's ports and harbors for fishing, transportation and recreation; [1985, c. 794, Pt. A, § 11 (new).]
2. Marine resource management. Manage the marine environment and its related resources to preserve and improve the ecological integrity and diversity of marine communities and habitats, to expand our understanding of the productivity of the Gulf of Maine and coastal waters and to enhance the economic value of the State's renewable marine resources; [1985, c. 794, Pt. A, § 11 (new).]
3. Shoreline management and access. Support shoreline management that gives preference to water-dependent uses over other uses, that promotes public access to the shoreline and that considers the cumulative effects of development on coastal resources; [1985, c. 794, Pt. A, § 11 (new).]
4. Hazard area development. Discourage growth and new development in coastal areas where, because of coastal storms, flooding, landslides or sea-level rise, it is hazardous to human health and safety; [1985, c. 794, Pt. A, § 11 (new).]
5. State and local cooperative management. Encourage and support cooperative state and municipal management of coastal resources; [1985, c. 794, Pt. A, § 11 (new).]
6. Scenic and natural areas protection. Protect and manage critical habitat and natural areas of state and national significance and maintain the scenic beauty and character of the coast even in areas where development occurs; [1985, c. 794, Pt. A, § 11 (new).]
7. Recreation and tourism. Expand the opportunities for outdoor recreation and encourage appropriate coastal tourist activities and development; [1985, c. 794, Pt. A, § 11 (new).]
8. Water quality. Restore and maintain the quality of our fresh, marine and estuarine waters to allow for the broadest possible diversity of public and private uses; and [1985, c. 794, Pt. A, § 11 (new).]

9. Air quality. Restore and maintain coastal air quality to protect the health of citizens and visitors and to protect enjoyment of the natural beauty and maritime characteristics of the Maine coast. [1985, c. 794, Pt. A, § 11 (new).]

The Maine Coastal Program is administered by the State Planning Office, and is a collaborative effort between state, regional, local and private organizations such as land trusts and economic development groups. Precisely because of its networked nature among many different entities, this program provides a good overview of the state-level sphere of coastal wetlands management. It consists of basically two general components, one that encourages good coastal stewardship and one that mandates it through enforceable policies.

Additionally, the York River Estuary is specifically listed as a Non-Point Source Priority Watershed under the Priority Coastal Watersheds Initiative. This designation is based on low dissolved oxygen, commercial resource value and medium ecological value of the estuary, and acts to direct state resources toward addressing non-point source pollution in the watershed in partnership with local organizations.

Under the Maine Coastal Program (MCP), encouragement of good coastal stewardship takes many forms. The State Planning Office, in collaboration with other departments and municipalities, administers several volunteer monitoring and educational programs. Two of these programs active in the town of York are Beach Profiling (erosion monitoring) and Maine Healthy Beaches (monitoring of bacterial levels at swim beaches). The MCP also offers grants for a variety of projects aimed at improving water quality. Active pursuit of these resources, when applicable to protecting York's tidal wetlands, would be an appropriate part of a town-level tidal wetlands management program.

The enforceable policies of the Maine Coastal Program that relate to managing the York River coastal wetlands are diverse and outlined below. Items dealing with air quality, solid or oil waste, nuclear facilities and hydropower have been removed as not directly relevant to York River wetlands.

Natural Resources Protection Act

The Natural Resource Protection Act (NRPA) (38 MRSA §§480-A to 480-S; 480-U to 480-Z) is actively enforced in the town of York by the Maine DEP, comprising the following regulations:

- Wetlands Protection Rules (DEP rules ch. 310): Regulates (in most cases prohibits) activities in wetlands such as filling or disturbing, sets standards for compensation, and defines terms.
- Permit by Rule Standards (DEP rules ch. 305): Refers to activities regulated by the state Natural Resources Protection Act. If the activity is not specifically mentioned in the act, an individual permit will be required. 55 pages.
- Significant Habitat Rules (DIFW rules ch. 10): Creates definitions relating to "significant wildlife habitats." Defines terms for endangered species habitat, high and moderate value deer wintering areas, high and moderate value travel cor-

ridors, high and moderate value waterfowl and wading bird habitat, shorebird nesting/feeding/staging areas, seabird nesting areas. DEP rules ch. 335: outlines permit requirements for above, applies to areas within 75 feet of "significant wildlife habitat" York River wetlands do not appear to have any of the above designations.

- Scenic Impact Rules (DEP rules ch. 315) Defines areas of local, statewide and national significance, including National Wildlife Refuges, the Atlantic Ocean, historic places, etc. Requires applicants for a NRPA permit to demonstrate that the scenic qualities will not be compromised by the proposed activities.
- The Department of Marine Resources through its Permit Review Program additionally contributes to the implementation of the Maine Coastal Zone Management Act.

Mandatory Shoreland Zoning Law (38 MRSA §§435 to 449)

The administration of this act consists of Maine DEP creating guidelines (DEP rules ch. 1000) which municipalities must follow. The town of York's Shoreland Zoning is discussed later.

Other State Laws

- Site Location of Development Law (38 MRSA §§481 to 485-A; 486-A; 487-A to 490; 490-A to 490-Z; 23 MRSA §704-A (MDOT traffic movement permit). This law governs siting of all kinds of very large developments, and is generally administered by Maine DEP.
- Erosion Control and Sedimentation Law (38 MRSA §420-C): Requires erosion control when earth moving activity is undertaken, not including agricultural fields.
- Storm Water Management Law (38 MRSA §420-D) Administered by Maine DEP. Applies when one or more acres of a development site will be disturbed. Has different levels of standards depending on how much impervious surface or total disturbance will occur. Lists engineering standards for stormwater delivery to a coastal wetland (sheet flow, no more than 2" rise in water level as a result of two year storm, etc). Requires easements or covenants in certain cases where stormwater flow effects are felt beyond the property boundary.
- Subdivision Law (30-A MRSA §4401 to 4407): This state law is administered by the town of York. Requires municipal review of new subdivisions, setting general standards for pollution, water availability, traffic, aesthetic/cultural/natural values, financial and technical capacity, surface water quality, freshwater wetlands, impact upon neighboring municipalities, and "liquidation harvesting" (clear-cutting prior to sale).
- Protection and Improvement of Waters Act (38 MRSA §§347; 361 to 367; 371-A to 372; 410-N; 411 to 424; 451 to 455; 464 to 470) This covers point sources that potentially discharge toxic chemicals.

- Surface Water Toxics Control Program, (DEP rules ch. 530, section 5).
- Nutrient Management Act (7 MRSA Part 10): applies to large farms.
- Marine Resources Law (12 MRSA §§6171 to 6192; 6432-A): Refers to Department of Marine Resources, regulation of fisheries. York River upstream from Ramshead Point is closed to shellfishing (http://mainegov-images.informe.org/dmr/rm/public_health/closures/2.pdf). The area from Sewalls Bridge to the harbor is conditionally open in the winter season, excepting the area west of Harris Island which is closed (http://mainegov-images.informe.org/dmr/rm/public_health/closures/2-A.pdf
- Maine Endangered Species Act (12 MRSA §§12801-12809; 12 MRSA §10001, sub-§§19 and 62 (definitions)). Endangered species (DIFW rules ch. 8): The Maine Endangered Species Act allows the Maine Department of Inland Fisheries and Wildlife to designate through a public process Essential Wildlife Habitat, which bars state or municipal activities which would damage the habitat. Currently, this act does not apply to the town of York because no Essential Habitat has been designated in the town of York, although bald eagles and piping plovers, two species potentially protected by this designation, are suspected to breed in the town.

Maine Growth Policy

At the state level, laws are in place which set goals and regulations for all Maine towns regarding development in general and as it relates to coastal wetlands. Maine Revised Statutes Annotated (MRSA) Title 30-A, chapter 187 (§4301 - §4457), governs municipalities and counties in planning and land use regulations, and includes these series of laws pertaining to management of coastal wetlands.

Ten state goals are established under 30-A MRSA 4312.3, including the following three:

1. "To protect the quality and manage the quantity of the State's water resources, including lakes, aquifers, great ponds, estuaries, rivers and coastal areas" (30-A MRSA §4312.3.E). Each community must develop policies to keep water quality from declining, and, where already degraded, to improve water quality (see 38 MRSA §464 et seq, for water quality classifications).
2. "To protect the State's other critical natural resources, including without limitation, wetlands, wildlife and fisheries habitat, sand dunes, shorelands, scenic vistas and unique natural areas" (30-A MRSA §4312.3.F). Municipal policies regarding critical natural resources must be consistent with state law, and may be more stringent (30-A MRSA §4326.3-A.D).
3. "To promote and protect the availability of outdoor recreation opportunities for all Maine citizens, including access to surface waters" (30-A MRSA §4312.3.J). This is a requirement to encourage continued availability to traditional outdoor activities such as hunting, boating, fishing and hiking, and to encourage land management practices and restrictions to facilitate these activities (30-A MRSA §4326.3-A.I).

4. The state of Maine requires all towns to adopt a comprehensive plan (30-A MRSA §4326). The comprehensive plan is powerful document which must be approved by each community's legislative body (the voters of the town of York in this case) and which sets the policy directives of the town. Although it does not carry the force of law, its contents have legal ramifications. The town's zoning and growth ordinances must by law (30-A MRSA §4314.3) be consistent with the comprehensive plan, although a two year lag period is granted (30-A MRSA §4314.3.E).

Municipal Land and Water Management

The town of York has a long history of land use regulation and protection of its water resources. York Harbor Village Corporation (until 1975, an independent part of what is now the town of York) created the first zoning ordinances in Maine about 90 years ago, which were also among the first in the country. These ordinances limited what had been rapid growth and defined appropriate business activities in its jurisdiction. More recently, in the 1970's, York was one of the first municipalities in the state to apply shoreland zoning requirements. They have also adopted regulations that are more stringent than the minimums required by the state, and have a reputation for strict enforcement. In addition, large tracts of land around public drinking supplies have been bought by local water districts for conservation purposes. Complementing the municipal efforts, there are organizations active in the community focused on conservation, such at the York Rivers Association, the York Land Trust and the Mt. Agamenticus to the Sea Coalition.

In many ways, the town leads the southern Maine region in environmental efforts. It has made substantial investments in natural resource data collection, has a dedicated GIS department, and an internet mapping server (IMS), all uncommon for a Maine municipality. It recently conducted a study of riparian corridor conditions and impervious surfaces. The town also set the goal for itself of mapping all regulated wetlands, but this task remains incomplete. Perhaps most significantly, the town has created a dedicated environmental enforcement position, the Shoreland Resource Officer. This last step has been hampered by a concurrent reduction in staff in the Code Enforcement Office, so that the new Shoreland Resource Officer dedicates about half of his time to non-environmental issues.

Existing Blueprint: Town Comprehensive Plan

In York, the Planning Board is invested by the Town of York Home Rule Charter with the task of creating the comprehensive plan. The Board of Selectmen does not have any formal role in drafting the comprehensive plan, although they are acknowledged in the plan itself as highly influential in its implementation. York's first comprehensive plan was completed in 1970. The town is currently on its third comprehensive plan, but has adopted the practice of amending the existing plan rather than rewriting it as in the past. As mentioned above, state goals drive the development of each municipality's comprehensive plan.

Generally, the comprehensive plan calls for minimal development along the York River, most of which is residential. Zoning is mentioned as the primary tool for protecting coastal wetlands in the town. The Planning Board is given the lead role in maintaining or strengthening zoning protection. The entire town of York, except for the Route One corridor, was rezoned in conjunction with the current comprehensive plan. Environmental concerns, in tandem with the desire to protect open space, figured prominently in the rezoning goals. Explicitly mentioned are strengthening shoreland/wetland standards, increasing open space requirements for subdivisions, slowing the rate of growth by limiting the number of new units per year, identifying zones to be preserved as rural, and direct purchase of open space by the town. The comprehensive plan specifically advises against increasing regulatory complexity in the absence of town resources which "enable the timely and fair application of the standards." All of these goals potentially contribute to management of coastal wetlands in the town.

In response to the state-level goal of protecting water quality, the town of York has adopted town Goal 5.2: "protect and enhance the water quality of York's major surface water supplies, particularly the York River and Cape Neddick River." Currently this has been accomplished by placing most undeveloped areas the along the York River in a Resource Protection Sub-district of the Shoreland Overlay Zone, and most other areas are in the Limited Residential Sub-district (see zoning below for more details). For the future, the town is tasked with the immediate priority of adding all streams which drain into the York River in the Stream Protection Sub-district (currently most, but not all, are). Another immediate priority for the Planning Board is increasing the no-cut/no-clearing zone adjacent to the York River from a current 75' to 100', excepting currently maintained fields and clearings which now provide expansive views of the river.

The first town goal under state goal 6 (protection of habitat) is the protection of coastal and freshwater wetlands. Most proposals under this goal refer to freshwater wetlands, although one refers to merging the Shoreland and Inland Wetland Ordinances into one with the goal of incorporating sewer, public water and drainage requirements. The Planning Board is given the lead role on this mid-term priority. Furthermore, the significant burden from these regulations on applicants and town are noted. Additional town goals focus on promoting or requiring more open space in residential developments, particularly in the rural zones west of I-95.

Regulatory tools are also mentioned specifically in the comprehensive plan with regard to water quality and wetlands protection. Enforcing best management practices is a mid-term priority entrusted to the Planning Board and Code & Planning Department. The goal of eliminating the remaining overboard discharges to the York River was completed a few years ago. The comprehensive plan mentions possible increased fees from owners to help make enforcement of current reporting requirements to the state consistent rather than sporadic.

Regulation of use of the York River occurs through the town Harbor Board and the Harbor Master, all under the state and town goals governing marine resources. Under this section, a mid to long term priority for the Selectmen and the Harbor Master is to establish specific points of access for motorized and non-motorized watercraft to the York River, discouraging motorized access east of Sewalls Bridge. Likewise, limiting the number, size and location of docks in that upper stretch of the river is mentioned, while loosening dock regulations downstream to encourage motorized access in the lower portion of the river.

Two capital improvements relevant to the river include a boat pump out station in York Harbor and a non-motorized boat access point at Goodrich Park. Both are considered mid-range priorities.

Other non-regulatory tools for conservation and environmental protection are pursued through the comprehensive plan, such as partnership with private organizations and direct purchase of sensitive tracts of land by the town. The Mt. Agamenticus area, which includes most of the York watershed, is specifically mentioned in the comprehensive plan. Currently this area is cooperatively managed by the town of York, York Water District, State of Maine, Nature Conservancy, town of South Berwick and others. At present, this management is taking the form of identifying the resources most worthy of protection, with the eventual creation of a master plan. The Mt. Agamenticus area is not an explicit unit under town zoning, with conservation easements, direct ownership and public education being the primary methods for its conservation.

Municipal Tools: Planning, Zoning and Enforcement

As reviewed above, the town of York has a number of powers by which to protect its fringing marshes. It also is directed, and to some degree constrained by, a multitude of federal and state laws. Planning and enforcement of land use regulations, specifically shoreland and wetland ordinances, currently form the cornerstone of wetland management in York. Under current zoning, fringing marshes fall under the definition of "coastal wetland." Specifically, Article 11 of the York Zoning Ordinance provides language which effectively limits any use within wetlands to a few specifically mentioned activities. The allowed uses that apply to fringing marshes are access to adjacent surface water, harvesting of wild crops without soil disturbance, or in a very rare case, a utility crossing necessary to provide for a reasonable return on the lot which contains the fringing marsh. Essentially, town ordinance keeps people and development out of fringing marshes.

Protection of lands adjacent to fringing marshes is provided by the shoreland overlay district (Figure 39). This overlay extends 250 feet from all tidal waters, large ponds and large wetlands, and 75 feet from tributary streams. It consists of four subdistricts: Limited Residential, Mixed Use, Resource Protection and Stream Protection, the last two of which are highly restrictive. The limitations on land use within the four subdistricts are varied, including no new tilling of soil within 100 feet of tidal waters, no new structures within 100 feet of tidal waters, no manure storage within 75 feet of tidal waters, no new livestock grazing areas within 100 feet of tidal waters, erosion and sedimentation control measures within 250 feet of tidal waters, large ponds, and wetlands 4 acres or greater, and tight restrictions on vegetation clearing within either 100 or 75 feet of tidal waters, depending on the specific subdistrict. These rules substantially limit new land uses along the York River.

Although zoning provides a key preventative function, its inability to fix systemic problems once they are discovered, or to adapt quickly to changing conditions, means that it is an ill-suited partner to an environmental monitoring program. Zoning is fundamentally preventative in nature, with a limited ability to generate restoration during enforcement of individual violations. Land uses legally established in the past are typically "grandfathered," and can persist indefinitely. Zoning ordinances do not change rapidly. They are developed through many months of research, public hearings, and in the case of York, a public vote at most twice a year. The pace of change is measured in terms of years, because if an attempt at change fails, it is usually not re-proposed for at least twelve months, if ever.

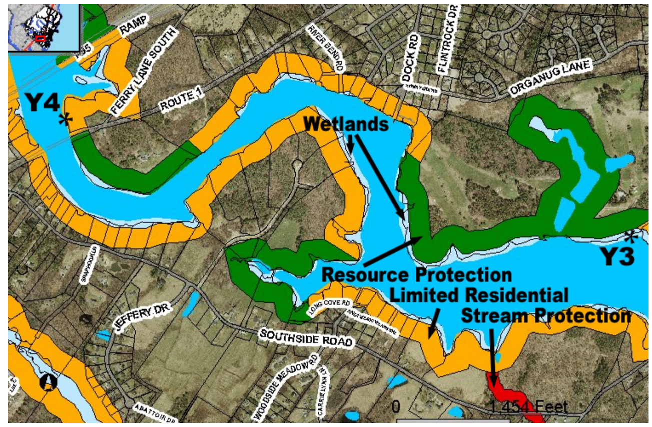


Figure 39: Detail of Town of York Zoning Map (online version) showing the Shoreland Overlay, a 250 foot buffer from the York River, and a 75 foot buffer from tributary streams. Land use is subjected to additional restrictions in this zone.

The state-mandated nature of shoreland zoning in Maine further limits the practicality of utilizing zoning to respond to signals generated by an environmental monitoring program. The Maine DEP is tasked with writing guidelines which towns must follow in creating their shoreland zoning. Although towns have the latitude to adopt different standards than the state mandates, those standards must be at least as stringent as the state's. In practice, towns tend to adopt standards which are substantially the same as the state standards. This saves towns considerable time and money, and creates uniformity from town to town, which reduces confusion and inadvertent noncompliance among developers who work in several towns. Although a town may adopt more stringent shoreland standards (and York has in some instances), there are barriers to straying too far from the state-mandated model.

Despite these weaknesses, the zoning ordinance can be amended if and when current patterns of development are shown to have damaged coastal wetlands. While existing development may resist change under new zoning, at least the little developable land that remains along the river will be held to a less harmful standard. Such standards could be based on a Land Use Index which is similar to that presented here, such that around fringing marshes, a certain LUI score must be maintained. More rapid changes may be possible under municipal ordinance if monitoring reveals a rapid decline in marsh condition. For example, in an emergency situation, application of fertilizer and pesticides on residential lawns and other sources of polluted runoff could be restricted, or revegetation of shoreland areas could be mandatory. These changes are easily reversible and would run less risk of "takings" litigation.

Conclusion

An environmental monitoring program should not exist in a vacuum, but instead should make human behavior responsive to real-world evolving conditions of natural resources. Zoning is the primary tool available to the municipality in managing its fringing marshes. Zoning provides a valuable preventative function in environmental management, and contains an enforcement aspect. An environmental monitoring program can indicate if zoning is adequately protective of coastal wetlands. The Land Use Index presented here offers one approach that could be incorporated into future zoning standards to prevent further damage in developing areas. However, once damage has been done, zoning, at least in its current form, may be unable to correct that damage. With threats to fringing salt marshes from global warming, sea level rise, non-point source pollution and marsh wasting diseases on the horizon, alternatives both within the zoning framework and beyond it should be explored. Some of the federal and state management programs that apply to coastal wetlands in York provide an opportunity for grant funding to the town, should it so desire. The town should continue to collaborate with research institutions, universities and non-profit conservation groups that seek to study and protect natural resources in town.

Management Recommendations

The fringing salt marshes along the banks of the York River are of high environmental quality, indicated by diverse plant communities and the presence of pollution-intolerant invertebrates at some sites. Zoning appears to have protected the adjacent upland from damaging forms of development. This success in land use management is indicated by moderate to high scores using the Land Use Index. Given this high environmental quality, management efforts should focus on preventing harm and protecting the resource.

The use of zoning as the primary environmental management tool is appropriate, since zoning is preventative in nature. Undeveloped lands within 250' of the normal high water line of the York River are generally in the most restrictive zoning category of "Resource Protection" under Shoreland Zoning. This designation, in essence, allows for one single-family dwelling per lot and some agricultural uses. The requirements of this zone will determine what becomes of the increasingly scarce and valuable undeveloped land along the York River.

Given the key role this zone plays in the future of York's coastal wetlands, it would be valuable to conduct a build-out analysis of the York River in terms of the Land Use Index presented here. The maximum development possible under current ordinance (and that which is already slated to occur under the growth cap) can be mapped and scored using the methodology presented here. Correlations developed in this paper can provide an estimate of what sort of ecological conditions would prevail if the York River uplands were fully developed as allowed by ordinance. The results could help guide conservation efforts, either by the Town or by organizations active in York such as the York Land Trust, the Nature Conservancy or Rachel Carson NWR. The results could also suggest dimensional regulations under zoning which have a basis in measured local conditions.

While environmental quality is currently good, there are certainly plausible threats to the York River's salt marsh on the horizon. Global warming, sea level rise, and increasing storminess each represent a potential to upset the ecological balance of York River wetlands. Another threat includes the slow underground migration of nutrients from septic systems into coastal waters on a decades-long scale, a phenomenon that has seriously degraded other New England estuaries such as Waquoit Bay on Cape Cod. In that estuary, algae clog the waters and diminish recreational and aesthetic value. The response of ecological systems is very difficult to predict, but can be detected easily through monitoring. But once detected, what will be the response?

The limits of zoning should be kept foremost in mind. Should environmental quality decline for whatever reason, amending the zoning ordinance will not bring back what has been lost. Such amendments might prevent further declines, but alternative tools that focus on changing existing conditions must be sought in any attempt to repair damage. A review of the existing wetland management framework for the York River highlights the central role of grants in environmental management, including restoration. The town of York should consider formalizing an environmental grant-seeking strategy. Environmental grants are generally collaborative in nature, involving diverse organizational partners and specialized roles. Regular meetings with research, education and conservation organizations, together with dedicated staff time and a clear willingness to work with other organizations and perhaps other municipalities can draw resources to York and build a foundation for environmental problem-solving. Such an approach will most likely become more and more essential through time.

References Cited

Allan, J.D. and A.S. Flecker. 1993. The influence of catchment land use on stream integrity across multiple special scales. Freshwater Biology. Vol 37:149-161.

Ayvazian, S.G., Deegan, L.A., and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. Estuaries 15:368-383.

Bertness, M.D., Ewanchuk, P.J., and B.R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. PNAS. 99(3):1395-1398.

Cabioch, L., Dauvin, J., Bermudez, J., and J. Babio. 1980. Effets de la maree noire de l' "Amoco Cadiz" sur le benthos sublittoral du nord de la Bretagne. Helgolander Meeresuntersuchungen, 33:192-208.

Carlisle, B.K., Smith, J.P. and A.L. Hicks. 2003. Cape Cod Salt Marsh Assessment Project Update: Land Use Association with Salt Marsh Condition 1999. Massachusetts Office of Coastal Zone Management. Boston, MA. 34 pp.

Carlisle, B.K., Baker, J.D., Hicks, A.L., Smith, J.P., and A.L. Wilbur. 2004. Relationship of Salt Marsh Indices of Biotic Integrity to Surrounding Land Use. Cape Cod Salt Marsh Assessment Project: Final Grant Report. Massachusetts Office of Coastal Zone Management. Boston, MA. 45 pp.

Comeleo, R.L., Paul, J., August, P., Copeland, J., Baker, C., Hale, S., and W. Latimer. 1996. Relationships between watershed stressors and sediment contamination in Chesapeake Bay estuaries. Landscape Ecology. Vol 11:307-319.

Dernie K.M., Kaiser, M., Richardson, E., and R. Warwick. 2003. Recovery of soft sediment communities and habitats following physical disturbance. Journal of Experimental Marine Biology and Ecology. Vol. 285-286:414-435.

Dionne, M., Short, F., and D. Burdick. 1999. Fish utilization of restored, created and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22:384-404.

Dionne, M., Haas, M., and A. Leonard. 2006. Developing an Index of Tidal Wetlands Health in the Gulf of Maine Using Fish as Indicators. Wells National Estuarine Research Reserve, Wells, ME. Environmental Protection Agency Small Grantees Program Project: 98187301:25.

Donnelly, J.P., and M.D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. Proceedings of the National Academy of Sciences 98(25):14218-14223.

Ferns, P.N., Rostron, D., and H. Simian. 2000. Effects of mechanical cockle harvesting on intertidal communities. Applied Ecology. Vol.37:464-474.

Gray, J.S. 1979. Pollution-induced changes in populations. Phil. Trans. R. Soc. La B (286):545-561.

Gross, M. F., Hardisky, M.A., Wolf, P.L., and V. Klemas. 1991. Relationship between aboveground and belowground biomass of *Spartina alterniflora* (smooth cordgrass). Estuaries 14:180-191.

Hiscock, K., O. Langmead, and R. Warwick. 2004. Identification of Seabed Indicator Species from Time-series and Other Studies Support Implementation of the EU Habitats and Water Framework Directives. Report to the Joint Nature Conservation Committee and the Environment Agency from the Marine Biological Association. Plymouth: Marine Biological Association. JNCC Contract F90-01-705. 109 pp.

Hughes, J.E., Deegan, L., Weaver, M., and J. Costa. 2002. Regional application of an index of estuarine biotic integrity based on fish communities. Estuaries 25(2):250–263.

Kneib, R.T. 1992. Population dynamics of the tanaid *Hargeria rapax* (Crustacea: Peracarida) in a tidal marsh. Marine Biology. Vol.113:437-445.

Kneib, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series. 106:227-238.

Levin L.A., and T. Talley. 2000. Influences of Vegetation and Abiotic Environmental Factors on Salt Marsh Invertebrates. Amsterdam, Netherlands. Kluwer Academic Publishers. 661-708.

Linthurst, R.A. 1980. An evaluation of aeration, nitrogen, pH and salinity as factors affecting *Spartina alterniflora* growth: a summary. In Estuarine Perspectives, edited by V. S. Kennedy. New York: Academic Press.

Massachusetts Geographic Information System. 2002. Land Use Data Layer. http://www.mass.gov/mgis/lus.htm. Accessed 1 March 2006.

Magurran, A.C. 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, NJ. 179 pp.

Marinucci, A. C. 1982. Trophic importance of *Spartina alterniflora* production and decomposition to the marsh-estuarine ecosystem. Biological Conservation 22:35-58.

Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. American Fisheries Society. Maryland, USA.

Minello, T.J., Able, K., Weinstein, M. and C. Hays. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density growth and survival through meta-analysis. Marine Ecology Program Service. 246:39-59.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York. 722 pp.

Morgan, P.A. and F.T. Short. 2000. Functions and Values of Salt Marshes in Northern New England: A Comparison of Fringing Marshes and Meadow Marshes. NOAA/NERR Report. 78pp.

Morgan, P.A., Curci, L., Dalton, C. and J. Miller. 2005a. Assessing the Health of Fringing Salt Marshes along the Fore River and its Tributaries. Natural Resource Damage Trustees, Maine Department of Environmental Protection Report. 39 pp.

Morgan, P.A., Dionne, M., MacKenzie, R. and L. Curci. 2005b. Ecological Functions and Values of Fringing Salt Marshes Susceptible to Oil Spills in Casco Bay. Maine Oil Spill Advisory Committee Report. 61 pp.

Morris, J.T. 1982. A model of growth responses by *Spartina alterniflora* to nitrogen limitation. Journal of Ecology 70:25-42.

Nixon, S. W. and C.A. Oviatt. 1973. Analysis of local variation in the standing crop of *Spartina alterniflora*. Botanica Marina. 16:103-109.

Neckles, H. and M. Dionne. 1999. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine: A GPAC Workshop.

Neckles, H. and B. Kopp. 2006. A Multi-scale Framework for Aquatic Habitat Indicators [Powerpoint presentation]. In: RARGOM Theme Session: Development of Ecosystem Indicators for Multiple Management and Research Needs. November 15, 2006. Wells National Estuarine Research Reserve, Wells, ME. http://www.rargom.org/meetings/Nov2006/RARGOMIndicatorWorkshop_Neckles.pdf Accessed May 20, 2007.

Pezeshki, S. R. and R.D. DeLaune. 1993. Effects of soil hypoxia and salinity on gas exchange and growth of *Spartina patens*. Marine Ecology Progress Series. 96:75-81.

Pocklington, P., and P. Wells. 1992. Polychaetes: key taxa for marine environmental quality monitoring. Marine Pollution Bulletin. 24(12):593-1992.

Roman, C.T., M. James-Pirri and J.F. Heltshe. 2001. Monitoring Salt Marsh Vegetation. Long-term Coastal Ecosystem Monitoring Program, Cape Cod National Seashore Wellfleet, MA.

Tupper, M. and K.W. Able. 2000. Movements and food habits of striped bass (*Morone saxatilis*) in Delaware Bay (USA) salt marshes: comparison of a restored and a reference marsh. Marine Biology 137:1049-1058.

Valiela, I., Collins, G., Kramer, J., Lajtha, K., Geist, M., Seely, B., Brawley, J., and J. Costa. 1997. Nitrogen loading from coastal watersheds applications. Ecological Applications. Vol. 7:358-380.

Weisberg, S.B., Dauer, D., Frithsen, J., and L. Schaffner. 1997. An Estuarine Benthic Index of Biotic Integrity (B-IBI) for Chesapeake Bay. Estuaries Vol. 20 No. 1:149-158.

Wigand, C., Comeleo, R., McKinney, R., Thursby, G., Chintala, M. and M. Charpentier. 2001. Outline of a new approach to evaluate ecological integrity of salt marshes. Human and Ecological Risk Assessment 7(5):1541-1554.

Wigand, C., McKinney, R., Charpentier, M., Chintala, M. and G. Thursby. 2003. Relationships of nitrogen loadings, residential development, and physical characteristics with plant structure in New England salt marshes. Estuaries 26(6):1494-1504.

Wilson, JG. 1994. The role of bioindicators in estuarine management. Estuaries. 17(1A):94-101.

Word, J.Q. 1990. The infaunal trophic index, a functional approach to benthic community analysis. Dissertation. University of Washington. Seattle, Washington. USA.

Young, T. and S. Sanzone (eds). 2002. A Framework for Assessing and Reporting on Ecological Condition: An SAB Report. EPA Science Advisory Board. Report no. EPA-SAB-EPEC-02-009. Washington,DC. (29 July 2003; www.epa.gov/sab).

Zar, J. 1996. Biostatistical Analysis. Prentice-Hall Inc., Upper Saddle River, NJ.

Appendix 1: Tables

Table A1. Site physical characteristics, including salinity, elevation and distance to the mouth of the river.

	Salinity						Site Elevation		Distance to Mouth of River
	JUNE		JULY		AUGUST				
Site	mean ‰	SE	mean ‰	SE	mean ‰	SE	ft*	SE	m
Y1	10.4	3.0	25.3	3.4	32.6	1.2	8.74	0.19	1422
Y2	30.1	0.3	31.5	0.5	35.7	1.4	7.80	0.24	1858
Y3	12.3	3.0	26.4	1.8	33.3	0.9	9.00	0.31	3120
Y4	19.6	2.5	27.9	1.6	26.1	2.2	9.26	0.25	5229
Y5	15.4	1.5	26.6	1.2	21.2	1.8	9.68	0.31	6382
Y6	11.7	2.4	22.7	1.6	nd	nd	8.05	0.40	7215

Table A2. Aboveground biomass (standing crop sampled in August). Site means and standard errors were calculated from nine stratified random quadrats.

	Live Biomass (g/m^2)		Dead Biomass (g/m^2)	
Site	Mean	SE	Mean	SE
Y1	147.3	17.0	20.6	5.7
Y2	100.2	15.8	13.6	3.0
Y3	126.1	15.6	37.8	16.5
Y4	117.9	14.9	36.2	12.5
Y5	153.0	21.5	93.8	27.9
Y6	134.2	23.8	60.9	17.0

Table A3a. Plant height (cm) and density (number stems per m^2).

Stem height (cm)

	Juncus gerardii		*Spartina alterniflora*		*Spartina patens*	
Site	Mean	SE	Mean	SE	Mean	SE
Y1	40.4	2.7	29.0	0.0	26.4	4.2
Y2	30.5	5.5	29.6	4.2	33.5	4.4
Y3	47.6	4.0	28.5	6.5	24.1	2.0
Y4	47.0	10.4	42.4	4.5	40.2	3.6
Y5	34.2	2.0	68.0	0.0	33.6	2.4
Y6	40.4	6.4	52.3	6.8	39.1	4.0

Table A3b. Plant density (number stems per m²).

Stem Density (no./m²)

	Juncus gerardii		*Spartina alterniflora*		*Spartina patens*	
Site	Mean	SE	Mean	SE	Mean	SE
Y1	909	130	244	nd	600	57
Y2	878	20	207	71	754	308
Y3	1368	218	323	105	831	189
Y4	1192	43	209	19	979	156
Y5	620	38	188	nd	1097	204
Y6	312	145	110	30	460	104

Table A4a. Invertebrates – Mean abundance and standard errors of invertebrate taxa by sample site, marsh zone, and class.

Site	Zone		Acari	Bivalvia	Copepoda	Gastropoda	Insecta	Malacostraca	Nematoda	Oligochaeta	Ostracoda	Polychaeta	Grand Total
Y1	High	mean	286	0	1575	0	1145	716	41375	79743	0	11167	136007
		SE	143	0	1145	0	573	516	12434	12693	0	2816	30321
	Low	mean	143	286	286	0	5297	286	14889	35505	0	62277	118970
		SE	143	286	286	0	3656	286	5943	8436	0	20297	39333
Y2	High	mean	143	0	143	0	2291	1002	27058	87188	0	5870	123695
		SE	143	0	143	0	1145	516	13893	16669	0	3120	35630
	Low	mean	0	931	0	0	143	24982	62993	28633	0	23694	141375
		SE	0	312	0	0	143	10873	11557	8789	0	9673	41347
Y3	High	mean	2863	0	0	0	2434	429	14317	73730	0	286	94059
		SE	1495	0	0	0	797	248	3545	21993	0	286	28364
	Low	mean	716	0	286	0	3293	716	21475	194561	0	6299	227346
		SE	379	0	286	0	2065	379	15132	85737	0	4874	108852
Y4	High	mean	143	0	716	0	2720	429	11596	62849	0	11453	89908
		SE	143	0	716	0	797	248	6658	32402	0	3545	44509
	Low	mean	143	286	0	0	8733	573	9592	25483	143	28347	73301
		SE	143	143	0	0	3236	379	3978	10445	143	1736	20203
Y5	High	mean	716	0	0	0	2577	573	7015	33787	0	1432	46099
		SE	143	0	0	0	1081	379	1613	3483	0	871	7570
	Low	mean	0	0	143	0	6013	429	34789	87903	143	19757	149178
		SE	0	0	143	0	2860	429	18425	32959	143	6033	60993
Y6	High	mean	2291	0	0	0	1861	0	2863	51110	0	6299	64424
		SE	758	0	0	0	1272	0	1575	25400	0	3198	32203
	Low	mean	0	0	0	143	4009	143	6729	105226	0	12599	128849
		SE	0	0	0	143	2533	143	4746	12612	0	3613	23791

Table A4b. Invertebrates – Mean abundance of invertebrate taxa per sample site.

Site	Mean abundance
Y1	127,488
Y2	132,535
Y3	160,703
Y4	81,604
Y5	97,639
Y6	96,636

Table A4c. Invertebrates – Total number of Invertebrates by marsh zone and site.

Site	Total High Marsh Abundnace	Total Low Marsh Abundance
Y1	408,020	356,910
Y2	371,084	424,126
Y3	282,178	682,038
Y4	269,723	219,902
Y5	138,297	447,534
Y6	193,273	386,546

Table A4d. Invertebrates – Mean numbers of taxa identified as either pollution tolerant or sensitive.

Site	Mean # Pollution Tolerant	Mean # Pollution Sensitive
Y1	3,150	25,770
Y2	20,938	27,166
Y3	573	2,004
Y4	3,865	13,601
Y5	215	5,941
Y6	72	1,575

Table A5a. Nekton – Densities of nekton sampled at six York River fringing salt marshes, summer 2005. Values are number of individuals per square meter of marsh surface.

Site	Month	Time	Green crab density	Shrimp density	Fundulus density	Tomcod density	Other fish density	Total fish density
Y1	June	Day	0.012	0.006	0.000	0.000	0.000	0.000
Y1	June	Night	0.013	0.032	0.000	0.003	0.011	0.013
Y1	August	Day	0.495	0.000	0.000	0.000	0.000	0.000
Y1	August	Night	0.907	0.006	0.000	0.000	0.019	0.019
Y1	**AVERAGE**		**0.357**	**0.011**	**0.000**	**0.001**	**0.007**	**0.008**
	SE		**0.216**	**0.007**	**0.000**	**0.001**	**0.005**	**0.005**
Y2	June	Day	nd	nd	nd	nd	nd	nd
Y2	June	Night	0.016	0.000	0.000	0.000	0.000	0.000
Y2	August	Day	0.017	0.004	0.000	0.000	0.030	0.030
Y2	August	Night	0.027	0.000	0.000	0.000	0.000	0.000
Y2	**AVERAGE**		**0.020**	**0.001**	**0.000**	**0.000**	**0.010**	**0.010**
	SE		**0.003**	**0.001**	**0.000**	**0.000**	**0.009**	**0.009**
Y3	June	Day	0.116	0.000	0.000	0.000	0.000	0.000
Y3	June	Night	0.087	0.019	0.000	0.000	0.000	0.000
Y3	August	Day	0.083	0.000	0.000	0.000	0.012	0.012
Y3	August	Night	0.260	0.000	0.000	0.000	0.000	0.000
Y3	**AVERAGE**		**0.136**	**0.005**	**0.000**	**0.000**	**0.003**	**0.003**
	SE		**0.042**	**0.005**	**0.000**	**0.000**	**0.003**	**0.003**
Y4	June	Day	0.042	0.000	0.000	0.000	0.000	0.000
Y4	June	Night	0.121	0.000	0.000	0.000	0.003	0.003
Y4	August	Day	nd	nd	nd	nd	nd	nd
Y4	August	Night	nd	nd	nd	nd	nd	nd
Y4	**AVERAGE**		**0.082**	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**
	SE		**0.028**	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**
Y5	June	Day	0.191	0.000	0.007	0.000	0.007	0.014
Y5	June	Night	0.011	0.002	0.000	0.000	0.004	0.004
Y5	August	Day	0.080	0.000	0.007	0.000	0.000	0.007
Y5	August	Night	0.022	0.000	0.075	0.000	0.168	0.243
Y5	**AVERAGE**		**0.076**	**0.000**	**0.022**	**0.000**	**0.045**	**0.067**
	SE		**0.041**	**0.000**	**0.018**	**0.000**	**0.041**	**0.059**
Y6	June	Day	0.048	0.000	0.000	0.000	0.000	0.000
Y6	June	Night	0.015	0.000	0.012	0.000	0.003	0.015
Y6	August	Day	nd	nd	nd	nd	nd	nd
Y6	August	Night	0.013	0.000	0.038	0.000	0.008	0.046
Y6	**AVERAGE**		**0.025**	**0.000**	**0.017**	**0.000**	**0.004**	**0.021**
	SE		**0.010**	**0.000**	**0.010**	**0.000**	**0.002**	**0.012**

Table A5b. Nekton – Total biomass, percent biomass and biomass density of nekton sampled at six York River fringe salt marshes, summer 2005. Biomass values are grams. Biomass densities are grams per square meter of marsh surface.

Site	Month	Time	Green crab biomass	Shrimp biomass	Fundulus biomass	Tomcod biomass	Other fish biomass	Total biomass	Green crab %biomass	Shrimp% biomass	Fundulus %biomass	Tomcod %biomass	Other fish %biomass	Area fished (m^2)	Green crab biomass density	Shrimp biomass density	Fundulus biomass density	Tomcod biomass density	Other fish biomass density	Fish biomass-density
Y1	June	Day	81.30	1.30	0.00	0.00	0.00	82.60	98.43	1.57	0.00	0.00	0.00	325.75	0.25	0.00	0.00	0.00	0.00	0.00
Y1	June	Night	126.70	5.90	0.00	1.80	18.00	152.40	83.14	3.87	0.00	1.18	0.12	370.45	0.34	0.02	0.00	0.00	0.05	0.05
Y1	August	Day	935.82	0.00	0.00	0.00	0.00	935.82	100.00	0.00	0.00	0.00	0.00	256.37	3.65	0.00	0.00	0.00	0.00	0.00
Y1	August	Night	2742.00	0.54	0.00	0.00	691.65	3434.19	79.84	0.02	0.00	0.00	0.20	315.41	8.69	0.00	0.00	0.00	2.19	2.19
Y1	**mean**		**971.46**	**1.94**	**0.00**	**0.45**	**177.41**	**1151.25**	**90.35**	**1.37**	**0.00**	**0.30**	**0.08**	**317.00**	**3.23**	**0.01**	**0.00**	**0.00**	**0.56**	**0.56**
	SE		**622.0**	**1.3**	**0.0**	**0.5**	**171.5**	**785.2**	**5.2**	**0.9**	**0.0**	**0.3**	**0.0**		**2.0**	**0.0**	**0.0**	**0.0**	**0.5**	**0.5**
Y2	June	Day	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Y2	June	Night	146.45	0.00	0.00	0.00	0.00	146.45	100.00	0.00	0.00	0.00	0.00	315.70	0.46	0.00	0.00	0.00	0.00	0.00
Y2	August	Day	76.17	0.36	0.00	0.00	14.17	90.70	83.98	0.40	0.00	0.00	0.16	233.93	0.33	0.00	0.00	0.00	0.06	0.06
Y2	August	Night	109.51	0.00	0.00	0.00	0.00	109.51	100.00	0.00	0.00	0.00	0.00	337.50	0.32	0.00	0.00	0.00	0.00	0.00
Y2	**mean**		**110.71**	**0.12**	**0.00**	**0.00**	**4.72**	**115.55**	**94.66**	**0.13**	**0.00**	**0.00**	**0.05**	**295.71**	**0.37**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
	SE		**20.30**	**0.12**	**0.00**	**0.00**	**4.72**	**16.37**	**5.34**	**0.13**	**0.00**	**0.00**	**0.05**		**0.05**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
Y3	June	Day	99.10	0.00	0.00	0.00	0.00	99.10	100.00	0.00	0.00	0.00	0.00	95.10	1.04	0.00	0.00	0.00	0.00	0.00
Y3	June	Night	289.41	0.00	0.00	0.00	0.00	289.41	100.00	0.00	0.00	0.00	0.00	206.25	1.40	0.00	0.00	0.00	0.00	0.00
Y3	August	Day	43.80	0.00	0.00	0.00	5.60	49.40	88.66	0.00	0.00	0.00	0.11	84.45	0.52	0.00	0.00	0.00	0.07	0.07
Y3	August	Night	579.90	0.00	0.00	0.00	0.00	579.90	100.00	0.00	0.00	0.00	0.00	150.15	3.86	0.00	0.00	0.00	0.00	0.00
Y3	**mean**		**253.05**	**0.00**	**0.00**	**0.00**	**1.40**	**254.45**	**97.17**	**0.00**	**0.00**	**0.00**	**0.03**	**133.99**	**1.71**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
	SE		**120.98**	**0.00**	**0.00**	**0.00**	**1.40**	**120.18**	**2.83**	**0.00**	**0.00**	**0.00**	**0.03**		**0.74**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
Y4	June	Day	119.60	0.00	0.00	0.00	0.00	119.60	100.00	0.00	0.00	0.00	0.00	306.05	0.39	0.00	0.00	0.00	0.00	0.00
Y4	June	Night	706.70	0.00	0.00	0.00	34.84	741.54	95.30	0.00	0.00	0.00	0.05	345.95	2.04	0.00	0.00	0.00	0.10	0.10
Y4	August	Day	390.01	0.00	0.00	0.00	0.00	390.01	100.00	0.00	0.00	0.00	0.00	nd						
Y4	August	Night	804.36	0.00	4.22	0.00	646.52	1455.10	55.28	0.00	0.29	0.00	0.44	nd						
Y4	**mean**		**505.17**	**0.00**	**1.06**	**0.00**	**170.34**	**676.56**	**87.65**	**0.00**	**0.07**	**0.00**	**0.12**	**326.00**	**1.22**	**0.00**	**0.00**	**0.00**	**0.05**	**0.05**
	SE		**156.01**	**0.00**	**1.06**	**0.00**	**158.94**	**289.06**	**10.85**	**0.00**	**0.07**	**0.00**	**0.11**		**0.83**	**0.00**	**0.00**	**0.00**	**0.05**	**0.05**
Y5	June	Day	98.19	0.00	1.50	0.00	2.00	101.69	96.56	0.00	1.48	0.00	0.02	141.03	0.70	0.00	0.01	0.00	0.01	0.02
Y5	June	Night	32.40	0.68	0.00	0.00	7.41	40.49	80.02	1.68	0.00	0.00	0.18	555.90	0.06	0.00	0.00	0.00	0.01	0.01
Y5	August	Day	77.72	0.00	12.40	0.00	0.00	90.12	86.24	0.00	13.76	0.00	0.00	150.20	0.52	0.00	0.08	0.00	0.00	0.08
Y5	August	Night	155.30	0.00	109.60	0.00	142.70	407.60	38.10	0.00	26.89	0.00	0.35	411.15	0.38	0.00	0.27	0.00	0.35	0.61
Y5	**mean**		**90.90**	**0.17**	**30.88**	**0.00**	**38.03**	**159.98**	**75.23**	**0.42**	**10.53**	**0.00**	**0.14**	**314.57**	**0.41**	**0.00**	**0.09**	**0.00**	**0.09**	**0.18**
	SE		**25.49**	**0.17**	**26.39**	**0.00**	**34.93**	**83.60**	**12.84**	**0.42**	**6.26**	**0.00**	**0.08**		**0.13**	**0.00**	**0.06**	**0.00**	**0.08**	**0.14**
Y6	June	Day	18.80	0.00	0.00	0.00	0.00	18.80	100.00	0.00	0.00	0.00	0.00	125.85	0.15	0.00	0.00	0.00	0.00	0.00
Y6	June	Night	28.49	0.00	13.23	0.00	54.46	96.18	29.62	0.00	13.76	0.00	0.57	323.06	0.09	0.00	0.04	0.00	0.17	0.21
Y6	August	Day	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Y6	August	Night	92.50	0.00	21.80	0.00	4.40	118.70	77.93	0.00	18.37	0.00	0.04	238.05	0.39	0.00	0.09	0.00	0.02	0.11
Y6	**mean**		**46.60**	**0.00**	**11.68**	**0.00**	**19.62**	**77.89**	**69.18**	**0.00**	**10.71**	**0.00**	**0.20**	**228.99**	**0.21**	**0.00**	**0.04**	**0.00**	**0.06**	**0.11**
	SE		**26.13**	**0.00**	**3.50**	**0.00**	**20.44**	**9.19**	**19.72**	**0.00**	**1.88**	**0.00**	**0.22**		**0.12**	**0.00**	**0.02**	**0.00**	**0.06**	**0.04**

Table A6a. Plant species percent cover at six York River fringing salt marsh sites. Values are means of nine stratified random sample quadrats per site.

	Site					
SPECIES	Y1	Y2	Y3	Y4	Y5	Y6
AgP			8.2			
AN				0.4		0.7
AP						
DS	13.78	4.2	7.6	28.0	14.7	5.1
FVs		1.1				39.1
GG	20.4	6.0	0.2		1.3	
GM	14.9	0.2	14.0		16.7	
JB					8.9	
JG	60.7	19.3	55.8	17.1	19.6	10.4
LN	0.2	1.6	0.2	0.4	0.4	1.1
PM	29.3					
SA	11.6	50.4	22.2	44.4	12.2	46.2
SE	3.6	10.4	3.8	10.2	3.1	2.2
SL	0.2	4.7				
SP	24.7	31.1	36.4	50.9	66.4	55.1
Spec					2.0	
SpM		3.8				
SS	6.4		4.7			
TM					13.1	

Table A6b. Plant species percent cover at six York River fringing salt marsh sites – Transect method. Values were calculated by determining the mean cover per species within sample quadrats along each transect and then averaging the transect values.

	Site					
Species	Y1	Y2	Y3	Y4	Y5	Y6
AgP	0.2	0.0	1.3		0.0	0.3
AN	0.9	6.4	0.0	0.0	0.0	0.0
Ans	0.0	0.0	0.4	0.1	1.1	2.5
AS	0.0	1.2	0.0	0.0	0.0	0.0
BS	0.0	0.0	0.7	0.0	0.0	0.0
BG	8.2	1.2	0.0	2.8	0.0	0.0
CP	0.0	0.0	0.0	0.0	0.1	0.0
DS	7.5	3.7	0.0	32.1	26.4	37.6
FVs	2.7	0.1	0.0	0.0	0.0	0.0
GG	10.5	0.2	10.8	0.0	2.0	0.0
GM	1.9	0.0	17.1	7.4	0.7	4.5
MG	0.0	0.0	2.4	0.0	0.1	0.0
JB	0.2	0.0	0.0	0.0	0.5	0.0
JG	29.9	7.1	48.3	33.3	10.2	0.0
LN	0.5	1.8	1.2	0.7	0.0	0.0
PA	2.3	0.0	0.4	0.0	0.4	3.7
PH	0.0	0.0	0.0	0.0	3.4	0.0
PM	7.0	15.2	1.9	1.9	0.0	5.7
Rosa	0.0	0.0	0.0	0.0	0.1	0.0
SA	33.7	65.6	33.2	37.9	24.9	38.3
ScM	0.0	0.0	0.0	0.0	0.1	0.0
ScR	0.0	0.0	0.0	0.0	0.1	0.0
SE	6.2	16.1	7.8	9.0	0.0	0.0
SL	0.6	4.9	0.0	0.0	0.0	0.0
SM	0.0	4.9	0.0	0.0	0.0	0.0
SP	18.5	33.9	12.6	13.1	42.5	13.9
Spec	0.9	0.0	10.2	2.9	1.6	0.0
SpM	0.9	0.0	10.2	2.9	1.6	0.0
SS	0.0	0.3	15.2	0.1	11.6	0.3
ST	0.0	0.0	0.3	0.0	0.0	0.0
TM	0.1	0.0	0.0	0.0	0.3	0.0
UKG#	0.4	0.0	0.0	0.0	0.0	0.0
UKG1	0.3	0.0	0.0	0.0	0.0	0.0
WRACK	0.6	0.0	0.0	0.0	0.7	0.0

Table A6c. Plant species abbreviations, scientific names and common names.

Field book abbreviation	Scientific name	Common name
AC	*Amaranthus cannabinus*	salt marsh hemp
AgP	*Agropyron pungens*	stiff-leaf quackgrass
Agr	*Agrostis sp.*	
AN	*Ascophyllum nodosum*	knotted wrack
ANs	*Ascophyllum nodosum 'scorpiodes'*	
AP	*Atriplex patula*	
AS	*Aster sp.*	aster
BG	*Bare Ground*	bare ground
BS	*Celastrus sp.*	bittersweet
CP	*Carex paleacea*	salt marsh sedge
DS	*Distichlis spicata*	spike grass
FV	*Fucus vesiculosus*	rockweed
GG	*Puccinellia maritima*	goose grass
GM	*Glaux maritima*	sea milkwort
IC	*Impatiens capensis*	jewelweed
JB	*Juncus balticus*	Baltic rush
JG	*Juncus gerardii*	blackgrass
LN	*Limonium nashii*	sea lavender
LS	*Lythrum salicaria*	purple loosestrife
MG	*Ipomoea sp.*	morning glory
NS	*Solanum sp.*	nightshade
PA	*Potentilla answerina*	silverweed
PH	*Phragmites sp.*	common reed
PM	*Plantago maritima*	plantain
PV	*Panicum virgatum*	switchgrass
Rosa	*Rosa rugosa*	rugosa rose
SA	*Spartina alterniflora*	cordgrass
ScM	*Scirpus maritimus*	salt marsh bulrush
ScP	*Scirpus pungens*	common three square
ScR	*Scirpus robustus*	salt marsh bulrush
SE	*Salicornia europeae*	glasswort
SL	*Suaeda linearis*	sea blite
SM	*Suaeda maritima*	sea blite
SP	*Spartina patens*	salt meadow hay
Spec	*Spartina pectinata*	rough cordgrass
SpM	*Spergularia marina*	salt marsh sand spurrey
SS	*Solidago sempervirens*	goldenrod
ST	*Solanum tuberosum*	poison night shade
TA	*Typha angustifolia*	narrow leaved cattail
TL	*Typha latifolia*	broad leaved cattail
TM	*Triglochin maritimum*	seaside arrow grass
UL	*Ulva lactuca*	sea lettuce

Table A7. Land Use Index – table of values for all sites. The 100 m buffer value was used in correlations with other parameters. The Rapid Assessment and Average values were part of the original methodology, but were not used in this study.

site	LUI - 100 m buffer (GIS analysis)	LUI - Rapid Assessment (field worksheet)	LUI Average
9	97.4	96.3	96.85
20	72.1	93.52	82.81
29	54.6	78.7	66.65
F1	20.3	80.56	50.43
F2	25.8	77.78	51.79
F3	56.4	82.41	69.41
Y1	78.3	74.07	76.19
Y2	76	81.48	78.74
Y3	80.7	73.15	76.93
Y4	84.9	85.19	85.05
Y5	73.2	75.93	74.57
Y6	70.1	75.93	73.02

Table A8a. Correlation results – Summary table of candidate indicators for plant productivity that correlate with LUI (100m) for 12 fringing salt marshes (York River, Fore River and Casco Bay sites). Also included are other variables with which they correlated.

Candidate Indicator	Variable	Pearson Correlation value
Aboveground biomass live (g/m^2)	LUI (100m)	-0.539
	Elevation†	+0.852
Stem height (cm) *Spartina alterniflora*	LUI (100m) †	-0.519
	Marsh width†	+0.722
	Soil porewater salinity†	-0.581
Stem height (cm) *Juncus gerardii*	LUI (100m) †	+0.623

† Correlation analysis done with York River sites only

Table A8b. Correlation results – Summary table of candidate indicators for nekton that correlate with LUI (100m) for 12 fringing salt marshes (York River, Fore River and Casco Bay sites). Also included are other variables with which they correlated.

Candidate Indicator	Variable	Pearson Correlation value
Green Crab %Biomass (GCPB)	LUI (100m)	+0.653*
	Distance to mouth of river (m) York River sites only	(-0.868)*
***Fundulus* %Biomass (FHPB)**	LUI (100m)	-0.812**
	Distance to mouth of river (m) York River sites only	(+0.834)*
***Fundulus* density (FHD)**	LUI (100m)	-0.773**
	Distance to mouth of river (m) York River sites only	(+0.799)
***Fundulus* Biomass Density (FHBD)**	LUI (100m)	-0.817**
	Distance to mouth of river (m) York River sites only	+0.724

Table A8c. Correlation results – Summary table of candidate indicators for macroinvertebrates. (York River, Fore River and Casco Bay sites). Also included are other variables with which they correlated.

Candidate Indicator	Variable	Pearson Correlation value
Percent *Neanthes* sp.	LUI (100m)	-0.693
Total densities of invertebrates	LUI (100m)	0.526
High marsh invertebrate densities	LUI (100m)	0.534

Table A8d. Correlation results – Summary table of candidate indicators for plant diversity that correlate with LUI (100m) for 12 fringing salt marshes (York River, Fore River and Casco Bay sites). Also included are other variables with which they correlated.

Candidate Indicator	Variable	Pearson Correlation value
Percent cover *Spartina alterniflora*	LUI (100m)	-0.714**
	Relative elevation (York River sites only)	-0.651
Percent cover *Distichlis spicata*	LUI (100m)	+0.661
	Relative elevation (York River sites only)	+0.679
	Relative elevation (Fore River/Casco Bay sites only)	+0.970
Shannon Weiner Index (H)	LUI (100m)	+0.779**
Evenness (E)	LUI (100m)	+0.926**

Note: * designates significant correlation at the 0.05 level; ** 0.01 level.

Appendix 2: Monitoring Plan

A Monitoring Plan for the Fringing Salt Marshes of the York River, Maine

Dr. Pamela Morgan
University of New England
Department of Environmental Studies
Biddeford, ME 04005

Christopher Cayce Dalton
Town of York
186 York Street, York ME 03909

Jeremy Miller
Wells National Estuarine Research Reserve
342 Laudholm Farm Road
Wells ME 04090

June 1. 2007

Table of Contents

I. Introduction

Description of Habitat

This monitoring plan was written for the Town of York to help in the management of its fringing salt marshes, which are located along the lower portion of the York River. The upstream portion of the river is surrounded by large, meadow marshes, which can be monitored using a variety of existing monitoring protocols, including the *Gulf of Maine Salt Marsh Monitoring Protocol*, *A Volunteer's Handbook For Monitoring Maine Salt Marshes,* and *A Volunteer's Handbook for Monitoring New England Salt Marshes* (all are listed in the resources section at the end of this document). However, as one travels downstream along the York River, the meadow marshes disappear and instead, the river is lined with fringing salt marshes. These marshes are long and narrow in shape, have steeper slopes, lower elevations and soils with less organic matter than those of larger marshes. Unlike larger salt marshes, which have extensive high marsh plant communities, fringing salt marshes have more equal proportions of high and low marsh plant communities (Morgan and Short 2000).

A fringing salt marsh along the York River

Fringing salt marshes are especially in need of monitoring because of their great susceptibility to environmental impacts. On their landward borders they are often abutted by residential and commercial development, and on their seaward borders they are exposed to the erosive force of waves. Because they are narrow, impacts to the borders of a fringing marsh have proportionately large effects on the entire marsh.

Goals and Applications

The **goal** of the monitoring recommended in this plan is to keep track of the status of the York River's fringing salt marshes over time, using methods that are relatively easy and inexpensive to employ.

Some of the **applications** of this monitoring effort might be to:

(1) Assess the effects of human disturbance (i.e. pollution, development) on the fringing salt marshes.
(2) Recognize signs of marsh degradation and then take actions to prevent further degradation.
(3) Select and prioritize marshes for conservation.

A Functions and Values Approach

During the summer of 2005, an EPA-funded study was conducted to develop indicators of fringing salt marsh "health" that would be responsive to the impacts of shoreline development along the York River (Morgan et al. 2007). This study used a functions and values approach, and focused on four salt marsh functions:

- ➤ Primary productivity
- ➤ Maintenance of animal (invertebrate) communities
- ➤ Provision of habitat for fish
- ➤ Maintenance of plant diversity

The indicators that were identified in this study are listed in the table below. These four functions and their associated indicators will form the basis of this Monitoring Plan.

Table 1. *Indicators of fringing salt marsh "health" that are responsive to increases in shoreline development. This list was generated from data collected at York River fringing salt marsh study sites (during summer 2005) and Casco Bay fringing salt marsh study sites (during summer 2004).*

Functions assessed	***Associated values***	***Indicators***
Primary productivity	Provides underlying support for estuarine & offshore food webs.	• Aboveground biomass (Live end-of-season standing crop) • Stem height of *Juncus gerardii* (black grass)
Maintenance of animal (invertebrate) communities	Supports shellfish & finfish production for recreational & commercial use; Supports estuarine & offshore food webs.	• Total invertebrate density (for entire marsh and/or for high marsh only) • *Mya arenaria* (softshelled clam) presence/density • *Neanthes* sp. density
Provision of habitat for fish	Provides nurseries for young fish, including many commercially important species, Supports finfish populations for estuarine & offshore food webs.	• *Fundulus heteroclitus* (common mummichog) percent biomass, biomass density &/or density • *Carcinus maenas* (green crab) percent biomass
Maintenance of plant diversity	Provides habitat for animal species, Provides unique biodiversity/ aesthetic value	• *Spartina alterniflora* (cordgrass) percent cover • Evenness index (E)

Note: For information about general salt marsh ecology, the importance of salt marshes and the threats to these marshes, please see the resources listed in the "Sources of Additional Information" section below, as these topics will not be addressed in this Monitoring Plan.

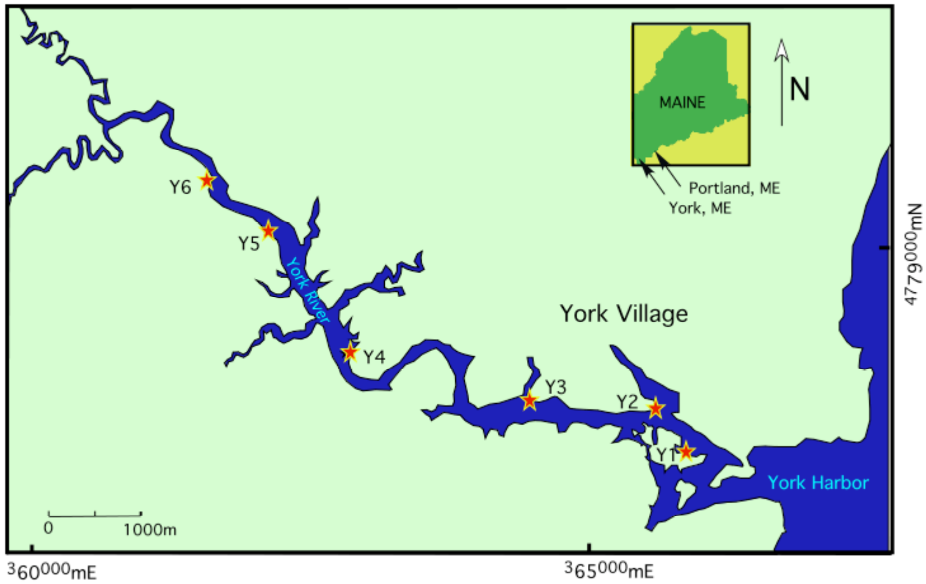
II. Sampling Design

Study Sites

Baseline data were collected for six fringing salt marshes along the York River in the summer of 2005. Therefore these six sites should continue to be monitored into the future. Additional sites could be added as a need arises or as resources become available. The locations of these six sites are listed in the table below and illustrated on the accompanying map. Note that unlike studies of larger, meadow marshes, where an "evaluation unit" must be identified in which sampling will take place, fringing marshes are small enough that the entire marsh may be considered the sampling unit. If the fringing salt marsh is more than 200m long, a portion of the marsh may be designated for sampling (150-250m in length).

Table 2. *GPS coordinates for fringing salt marsh study sites along the York River, York, Maine*.

Site Number	Site Name	Start Point	End Point
Y1	Wiggly Bridge	N 430 08.200', W 0700 39.015'	N 430 08.209', W 0700 39.150'
Y2	Harris Island Road	N 430 07.947', W 0700 38.854'	N 430 07.936', W 0700 38.709'
Y3	Golf Course	N 430 08.278', W 0700 40.044'	N 430 08277', W 0700 39.938
Y4	Goodrich Park	N 430 08.5', W 0700 41.503'	N 430 08.565', W 0700 41.514'
Y5	Riverwood	N 430 09.247', W 0700 42.111'	N 430 09.163', W 0700 42.048'
Y6	Scotland Bridge	N 430 09.549'. W 0700 42.619'	N 430 09.9498', W 0700 42.645'



Location of six fringing marsh sample sites along the York River

Sampling design within each study site

An important aspect of a monitoring program is the location of sample points within a marsh site. Depending on the specific objectives of the monitoring, the sampling design used to collected data about the four functions listed in Table 1 above may vary. Is the purpose to compare present conditions to baseline conditions? Do results need to be analyzed using specific statistical methods? How much time is available to do the sampling and to process the results? Will the results be used in more regional monitoring projects as well, such as those currently underway for salt marshes in the Gulf of Maine? These questions will need to be addressed before a sample design is selected. It is therefore recommended that a salt marsh ecologist be consulted before monitoring begins.

The sampling design and methods that will be presented here can be used as a starting point. They are the methods that were used to collect baseline data in the summer of 2005, and so are certainly applicable to the monitoring goal of tracking the status of the marshes over time. A table illustrating the recommended sampling methods and the frequency of sampling is included here. It is modeled after the GPAC Monitoring Protocol, but differs from it in many respects. Due to the small size of fringing salt marshes compared to larger meadow marshes, several of the specific sampling methods recommended in the GPAC Protocol are not useful in sampling fringing salt marshes. A comparison of the GPAC Monitoring Protocol and the York River Fringing Salt Marsh Monitoring Protocol is included in the Appendix.

Table 3. Summary of York River Fringing Salt Marsh Monitoring Protocol *(Adapted from GPAC Protocol http://www.gulfofmaine.org/habitatmonitoring/saltmarshprotocol.php).*

Indicator	Variable Name	Description	Sampling Method	Annual Sampling Frequency
Soils and Sediments				
	Pore-water salinity	Parts dissolved salts per thousand (also referenced to Practical Salinity Scale) of soil water collected from 5-25 centimeter depths	Groundwater wells, soil cores, or sippers	At minimum, three early- and mid-growing season sample should be taken.
Vegetation				
• *Spartina alterniflora* (cordgrass) percent cover • Evenness index (E)	Composition	Identity of all plant species occurring per square meter	Nine stratified random 1m^2 quadrats per site *OR* 1m^2 quadrats sampled every 10m along randomly located transects (spaced at > 10-meter intervals)	Mid-late July preferred
	Abundance	Percent cover per square meterby species		
Nekton				
• *Fundulus heteroclitus* (common mummichog) percent biomass, biomass density &/or density • *Carcinus maenas* (green crab) percent biomass	Composition	Identity of each animal sampled	Fyke nets (chambered trap nets) set up at marsh edge. Stake out high tide line and measure area of marsh flooded that drained into nets. Count number of fish by species. Record weight of up to 30 individuals of each species (including green crabs) from each sample.	Sample consecutive day and night spring tides in June and August.
	Density	Number of fish (and green crabs) by species per square meter		
	Biomass	Mass of fish (and green crabs) by species		
Invertebrates				
• Total invertebrate density (for entire marsh and/or for high marsh only) • *Mya arenaria* (softshelled clam) presence/density • *Neanthes* sp. density	Density of all organisms	Number of invertebrates per square meter in each vegetated zone	Three 4 cm deep cores sampled in each vegetated marsh zone (high marsh, low marsh and *Phragmites*, if present) Count all invertebrates per sample Identify, sort and count *Mya arenaria* and *Neanthes* sp. in sample cores	June
	Density of *Mya arenaria* and *Neanthes* sp.			
Primary productivity				
• Aboveground biomass (Live end-of-season standing crop) • Stem height of *Juncus gerardii* (black grass)	Aboveground biomass	End-of-season live standing crop per square meter	Nine stratified random 1/4m^2 quadrats per marsh site	Late August
	Stem height	Height of 5-10 random *Juncus gerardii* stems in 1/4m^2 quadrats where it is the dominant plant species		

Locating stratified random points

At each of the fringing marsh sites, nine sample points should be established according to the proportion of high marsh to low marsh at each site. These nine sample points will be used to sample salinity, plant diversity, and aboveground biomass.

One method to determine the proportion of high to low marsh is as follows: Establish five equally spaced transects across the width of the marsh, running perpendicular to the shoreline. The spans of both the high marsh and low marsh areas should then measured along each of these transects, and the total amounts of high and low marsh calculated and compared to estimate the percent of low and high marsh at each site. These calculated percents should then be used to proportionally distribute the nine sample points between the high and low marsh areas.

III. Monitoring Protocols

Salinity

Soil porewater should be extracted using soil sippers made of 1/4" PVC pipe inserted into the marsh to a depth of 15 cm. Holes drilled in the PVC allows water from 10-15 cm below the soil surface to enter the sipper. The salinity of the water extracted is then determined using a standard refractometer. Samples should be taken at least three times at each site, once each in the early and mid-growing seasons (May, June and July).

Aboveground production of salt marsh vegetation

End-of season standing crop

Primary production of vascular plants at each site should be determined by measuring the end-of-season standing crop (the live aboveground plant biomass) in early August. Samples should be collected from each marsh site at the nine stratified random points described above. All vegetation in a 0.25 m^2 quadrat at each sample point should be clipped. Live plants are then separated from dead material. Samples are dried at 60^0C for 48 hours and weighed to determine g/m^2 of biomass.

Juncus gerardii *plant heights*

Before drying the samples collected for end-of-season standing crop, any samples that were completely or wholly *Juncus gerardii* should be identified. Within each of these samples, ten shoots should be randomly selected and heights measured. Alternatively, these height measurements could be done when in the field, when aboveground biomass is sampled. A mean height of *Juncus gerardii* plants should be calculated.

From the plant aboveground biomass data collected, the following should be calculated:

1. Aboveground biomass (Live end-of-season standing crop)
2. Stem height of *Juncus gerardii* (black grass)

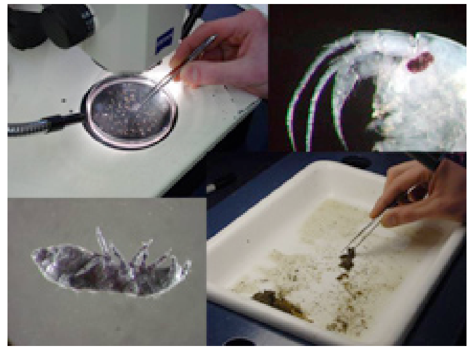

*Sampling aboveground biomass; Black grass (*Juncus gerardii*)*

Benthic invertebrates

Benthic invertebrates should be sampled in June in each vegetated zone of the six marsh sites (low marsh, high marsh and *Phragmites*, if present). Three 7.8 cm diameter cores should be taken in each vegetated zone, in close proximity to the nine sample points described above, if possible. The top 4 cm of substrate of each core should be collected and transported in coolers to the lab, where the samples can be temporarily stored in 70% ethanol. Samples can later be broken up and sifted through a 2 mm and then a 0.5 mm sieve to remove fine sediment. They should then be divided into four equal parts, and two of these subsamples should be analyzed. Each subsample should be stained using Rose Bengal sodium salt for easier separation of invertebrates from the substrate. All invertebrates 0.5 mm or greater can then be removed from the substrate using forceps and transported to a 20 ml scintillation vial containing 70% ethanol.

From the invertebrates collected, three things are needed:

1. A count of the total number of invertebrate organisms in each high marsh and low marsh sample.
2. A count of the number of softshelled clams (*Mya arenaria*) present in each high marsh and low marsh sample.
3. A count of the number of *Neanthes sp*. worms present in each high marsh and low marsh sample.



Coring for invertebrates; sorting invertebrates.

Nekton (Fish and Macrocrustaceans)

Fish utilization of vegetated marsh is to be measured using fyke nets (chambered trap nets), which capture fish non-destructively. Each site should be sampled during consecutive day and night spring tides in June and August. Net openings are 1.2 m^2 opening with two 15m long wings. The net opening is set at the lower edge of the vegetated marsh, with the wings set into the marsh at 30^0 to 45^0 from the line described by the lower edge. The wings are then extended at an angle from the net opening into the marsh, delineating a triangle of habitat. The wing lead lines are then staked to the substrate, and the wings held down to the marsh surface by modified lawn staples connected by a rope. When the incoming tide reaches its furthest extent, the tide line above the net should be flagged, and the wings released by pulling the stakes out via the rope so the float lines pop to the surface, and the wings form vertical net walls to direct fish into the center net segments (fykes) as the tide recedes. Fish are then collected from the cod end 2 to 4 hours later, once the tide has receded below the level of the first fyke. Green crabs are separated from fish immediately to minimize predation during measurement. The area of flooded marsh that drains into the net (as delineated by the wings and the marked high tide line) is then measured. The wings are then again secured to the marsh surface and sampling is repeated during the night tide.

All fish and crustaceans should be counted and identified to species (if possible), and total biomass of each species measured. At a minimum, green crabs and mummichogs should be counted and their biomass measured. Up to 30 individuals of each fish species should be sampled haphazardly from a bucket with an aquarium net.

From the fish and crabs collected, the following should be recorded or calculated:

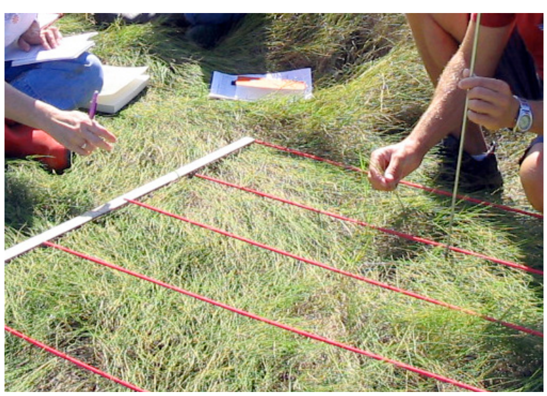
1. *Fundulus heteroclitus* (common mummichog) percent biomass, biomass density &/or density.
2. *Carcinus maenas* (green crab) percent biomass, biomass density &/or density.


*Fyke net set up during sampling; Common mummichog (*Fundulus heteroclitus)

Plant diversity

Plant diversity sampling should occur during the month of July. The point intercept method used by the National Park Service is recommended (http://www.nature.nps.gov/im/monitor/protocoldb.cfm). Percent cover of individual species in $1m^2$ quadrats should be determined at each of the nine stratified random sampling points.

Alternatively, plants can be sampled using a transect method modified from what is described in the GPAC Protocol (www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf) and what has been used in previous studies by the Massachusetts Office of Coastal Zone Management (http://www.mass.gov/czm/wetlandassesscape.htm). Transects are randomly located along the seaward length of each marsh. To determine the number of transects per site, divide the length of each marsh by 20 m. Transects should run from the seaward edge of each site to the upland edge. Compass bearings of all transects should be recorded. Beginning at the seaward end of each transect, the point intercept method is used to determine percent cover of individual species in $1m^2$ quadrats, which should be spaced 10 m apart along the transects. In addition, a quadrat should be sampled at the upland edge of the marsh.




Using the NPS point intercept method to sample in $1m^2$ quadrats; Laying out transects in a fringing marsh.

From the plant composition data collected, the following should be calculated:

1. *Spartina alterniflora* (cordgrass) percent cover
2. Evenness index (E)

IV. Schedules and Priorities

It is commonly recommended that monitoring of salt marsh habitats take place once every five years. This is a good guideline to use for the York River's fringing salt marshes as well. Of course if a concern about the marshes or about a particular fringing marsh arises, then the methods presented here can be used on an as-needed basis. However it must be recognized that decisions about when and what to monitor are often based not on what is be best for the health of the particular habitat, but on what is economically feasible or on what time will permit. Plant sampling, for example, is relatively easy and inexpensive, and can often be carried out by trained volunteers. Invertebrate sampling, on the other hand, is more time and equipment intensive and may require a higher level of expertise. Although this Monitoring Plan was developed to include methods that are relatively inexpensive to use, and that trained volunteers should be able to carry out, we recognize that resources are limited. The table below therefore lists the components of this Monitoring Plan, with information about the difficulty of employing each indicator *and* the effectiveness of each indicator.

Table 4. *Indicators of fringing salt marsh "health," including difficulty level of sampling and processing; and responsiveness to shoreline development pressures.*

Functions assessed	***Indicators***	***Level of sampling & processing difficulty 1easy- 5 difficult***	***Response to shoreline development pressures***
Primary productivity	• Aboveground biomass (Live end-of-season standing crop)	3	Very good
	• Stem height of *Juncus gerardii* (black grass)	1	Good
Maintenance of animal (invertebrate) communities	• Total invertebrate density (for entire marsh and/or for high marsh only)	5	Good
	• *Mya arenaria* (softshelled clam) presence/density	4	Good
	• *Neanthes* sp. density	4	Good

Provision of habitat for fish	• *Fundulus heteroclitus* (common mummichog) percent biomass, biomass density &/or density	4	Good
	• *Carcinus maenas* (green crab) percent biomass	4	Very good
Maintenance of plant diversity	• *Spartina alterniflora* (cordgrass) percent cover	1	Very good
	• Evenness index (E)	1	Excellent

V. Local Resources

The following people can provide information and help concerning the various components of this Monitoring Plan:

Christopher Cayce Dalton Town of York 186 York Street, York ME 03909	Fish sampling, data analysis
Jeremy Miller Wells National Estuarine Research Reserve 342 Laudholm Farm Road Wells ME 04090	Invertebrate sampling, fish sampling
Dr. Pamela Morgan Department of Environmental Studies University of New England Biddeford, ME 04005 pmorgan@une.edu	Study design, vegetation sampling, data analysis

VI. Sources of Additional Information

Bottitta, G. and K. Whiting-Grant. 2004. A Volunteer's Handbook For Monitoring Maine Salt Marshes.
Available from: http://www.seagrant.umaine.edu/extension/eh.htm

Carlisle, B.K., A.M. Donovan, A.L. Hicks, V.S. Kooken, J.P. Smith, and A.R. Wilbur. 2002. A Volunteer's Handbook for Monitoring New England Salt Marshes. Massachusetts Office of Coastal Zone Management, Boston, MA.
www.state.ma.us/czm/volunteermarshmonitoring.htm

Morgan, P.A. and F.T. Short. 2000. Functions and Values of Salt Marshes in Northern New England: A Comparison of Fringing Marshes and Meadow Marshes. NOAA/NERR Report. 78pp.

Morgan, P.A., C. Dalton, J. Miller and M. Dionne. 2007. A Comprehensive Wetland Program for Fringing Salt Marshes in the York River, Maine. EPA New England Report.

Neckles, H.A. and M. Dionne. 2000. Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells ME.
http://restoration.nos.noaa.gov/htmls/resources/general_pubs.html#N

Roman, C.T., M. James-Pirri and J.F. Heltshe. 2001. Monitoring Salt Marsh Vegetation. Long-term Coastal Ecosystem Monitoring Program, Cape Cod National Seashore Wellfleet, MA.
http://www.nature.nps.gov/im/monitor/protocoldb.cfm

Taylor, P.H. (ed.) 2005. Salt Marshes of the Gulf of Maine: Long-term Monitoring to Assess Human Impacts and Ecological Condition. Gulf of Maine Council on the Environment.
www.gulfofmaine.org/habitatmonitoring

Appendix

Table A1. Comparison of York River Fringing Salt Marsh Monitoring Protocol with GPAC Protocol (http://www.gulfofmaine.org/habitatmonitoring/saltmarshprotocol.php). White boxes are from the GPAC protocol, green boxes are from Fringing Salt Marsh Protocol.

Variable Name	Description	Sampling Method	Annual Sampling Frequency
Soils and Sediments			
Pore-water salinity	Parts dissolved salts per thousand (also referenced to Practical Salinity Scale) of soil water collected from 5-25 centimeter depths	Groundwater wells, soil cores, or sippers	For all projects, at low tide between early (April/May) and mid- (July/August) growing seasons, including spring/neap tides (6 times per year)
Pore-water salinity			Above is ideal, at least an early- and mid-growing season sample should be taken
Vegetation			
Composition	Identity of all plant species occurring per square meter	Permanent or temporary plots (0.5-1 square meter) positioned random-systematically across the entire marsh or stratified by elevation (low marsh, high marsh, and upland edge) along transects running perpendicular to the main tidal channel at > 10-meter intervals starting at a random distance within first interval, at impacted/restored and reference sites.	For all projects, at time of maximum standing biomass: mid-July through August (once per year)
Abundance	Percent cover per square meter by species		
Height	Mean height of 3 tallest individuals of each species of concern per square meter		
Density	Number of shoots per square meter in plots restricted to species of concern	Permanent plots established within distinct stands of species of concern	
Abundance	Percent cover per square meter by species	Nine stratified random 1m2 quadrats per site OR 1m2 quadrats sampled every 10m along randomly located transects (spaced at > 10-meter intervals)	Same as above ***Note***: Data collected will be used to calculate Evenness Index and percent cover *Spartina alterniflora*
Nekton			
Composition	Identity of each animal sampled	Methods apply to all variables: Seine and block nets (0.25inch mesh) in larger creeks and channels at impacted/ restored and reference sites (3 tows, 10-15 meters long/site). Record length, average width, average depth of towed area. And Throw traps or lift nets in pools and throw traps, lift or ditch nets (all 0.125-inch mesh) in small creeks or ditches at impacted/restored and reference sites (5 pool and 5 creek and/or 5 ditch samples/site). Record length, width and avg. depth of sample.	For all projects, at mid-tide during a spring tide in August (once per year)
Species richness	Total number of species represented		
Density	Number of animals per square meter		
Length	Length (fish, shrimp) or width (crabs) of 15-20 individual animals (randomly selected) per species, to nearest 0.5 millimeter		
Density	Number of fish (and green crabs) by species per square meter	Fyke nets (chambered trap nets) set up at marsh edge. Stake out high tide line and measure area of marsh flooded that drained into nets. Count number of fish by species.	Sample consecutive day and night spring tides in June and August. ***Note***: Data will be used to calculate *Fundulus heteroclitus* (common

Biomass	Mass of fish (and green crabs) by species	Record weight of up to 30 individuals of each species (including green crabs) from each sample.	mummichog) percent biomass, biomass density &/or density & *Carcinus maenas* (green crab) percent biomass
Invertebrates			
Mosquitoes	Number of mosquito larvae and pupae per square meter	Permanent stations in pool/wet areas, with 3 dips of 350-milliliter cup in 3-meter-radius circles, at impacted/restored and reference sites (10 dip stations/site)	For all projects, at low tide, weekly from May-September (12-15 times per year)
Density of all organisms Density of Mya arenaria and Neanthes sp.	Number of invertebrates per square meter in each vegetated zone	Three 4 cm deep cores sampled in each vegetated marsh zone (high marsh, low marsh and Phragmites, if present) Count all invertebrates per sample Identify, sort and count Mya arenaria and Neanthes sp. in sample cores	June ***Note:*** Data will be used to calculate overall invertebrate density, plus *Mya arenaria* and *Neanthes* sp. density
Primary productivity			
Aboveground biomass	End-of-season live standing crop per square meter	Nine stratified random 1/4m2 quadrats per marsh site	Late August
Stem height	Height of 5-10 random *Juncus gerardii* stems in 1/4m^2 quadrats where it is the dominant plant species		

Complete, original GPAC Protocol:
www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf