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# Ecological Functions and Values of Fringing Salt Marshes Susceptible to Oil Spills in Casco Bay, Maine

by

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# EXECUTUVE SUMMARY

Casco Bay is the largest oil port in Maine and northern New England, handling over 20 million tons of crude oil and oil products annually. The susceptibility of the Bay's estuarine habitats, especially its fringing salt marshes, to potential spill events was the impetus for this study. Although much has been learned to date about the effects of oil spills on estuarine habitats around the world, there is a real need for site-specific knowledge of the structures and functions of local habitats so that resource managers can be prepared in the event of a spill. Our study focused specifically on the value of Casco Bay's fringing salt marshes to shellfish and finfish production, to vegetation production and diversity, and as buffers against sea level rise and coastal erosion. The work we have accomplished has been the first study of the fringing salt marshes of Casco Bay that has explored the biotic communities (fish, invertebrates and plants) of these marshes in conjunction with the physical properties of these sites.

Nine fringing salt marshes were selected for study and mapped with GIS/GPS technology. The results of our survey of the physical characteristics of the nine fringing marsh sites (including site width, surface slope, fetch, elevations and salinity) demonstrated that wide variation occurs in these characteristics among fringing marsh sites.

Sediment deposition on the surface of these sites (short-term (2 wks) and long-term (14 mos) measurements) was similar to what has been observed in other fringing marshes in New England. The plant diversity of these sites varied greatly in the plant species present and the extent of coverage of those species from one fringing salt marsh to another. Even the percent of high marsh and low marsh varies substantially from site to site, with some sites being predominately high marsh communities and others almost exclusively low marsh. Two potentially invasive species were observed in a number of the Casco Bay sites we studied: *Phragmites australis* (common reed) and *Lythrum salicaria* (purple loosestrife). Plant productivity, as measured by end-of-season-standing crop, was similar at all but one site, averaging 70 g/m$^2$ in 2002 and 88 g/m$^2$ in 2003.

Large numbers of invertebrates were found in the upper 4 cm of soil at all fringing marsh sites. Densities in low marsh areas ranged from 3,643/m$^2$ to 11,673/m$^2$. At all but one site, the density of invertebrates was greater in the low marsh than in the high marsh. High marsh densities ranged from 1,840/m$^2$ to 16,174/m$^2$. The most common invertebrates found were species of Clitellata, Malacostraca and Nematoda. Thirteen finfish species and five decapod macrocrustacean species were collected from the fringing marsh study sites. Resident biomass densities exceeded those of the marine transient species by four fold. The green crab (*Carcinus maenas*) was present at all sites on all dates, and its biomass densities were ten fold higher than that of the next largest biomass group, the resident fishes.

Knowledge of these local fringing salt marsh habitats will be invaluable in improving the effectiveness of oil spill cleanup operations, accurate assessment of natural resource damages caused by spills, and the restoration of impacted sites. In addition, the data acquired in this study provide an initial set of benchmarks upon which to build a program to assess long-term change in Casco Bay tidal marsh habitats.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# ACKNOWLEDGEMENTS

This study was made possible by a grant from the Maine Oil Spill Advisory Council. Additional support was provided by the University of New England's College of Arts and Sciences Dean's Office and the Wells National Estuarine Research Reserve.

# INTRODUCTION

Casco Bay is the largest oil port in Maine and northern New England, handling over 20 million tons of crude oil and oil products annually (Port of Portland 2001). The terminals are in Portland Harbor and the Fore River, plus a terminal at Cousins Island serving the Wyman power plant. Although much has been learned to date about the effects of oil spills on estuarine habitats around the world, there is a real need for site-specific knowledge of the structures and functions of the local habitats so that resource managers can be prepared in the event of a spill. Knowledge of these local habitats will be invaluable in improving the effectiveness of oil spill cleanup operations, accurate assessment of natural resource damages caused by spills, and the restoration of impacted sites.

Because the extensive salt marshes lining the edges of the Casco Bay Estuary are predominantly fringing marshes, we focused our study on these important habitats. Fringing salt marshes form in protected areas along the edges of rivers and bays and are relatively narrow in shape (Bryan et al. 1997). Recent studies have highlighted the importance of fringing salt marshes (Morgan and Short 2000), which are valued for a number of reasons. Gulf of Maine salt marshes are prolific areas of primary production and are nursery grounds for finfish and shellfish. They also build up sediments and counter the effects of sea level rise, which aids in storm surge protection. In addition, they are valued for their recreational and aesthetic contributions to local seacoast communities (Wells NERR 2002, Dionne et al. 1999, Bryan et al. 1997, Teal 1986, Short 1992). Table 1 lists the primary functions and values of New England salt marshes. Our study focused specifically on the value of Casco Bay's fringing salt marshes to shellfish and finfish production, to vegetation production and diversity, and as buffers against sea level rise and coastal erosion.

The objectives of our study follow:

(1) Map the location and size of nine fringing marshes, and delineate high and low marsh plant communities at each site.
(2) Gather physical characteristic data at each site, including marsh surface slope, elevation and soil salinity.
(3) Investigate the sediment trapping ability of the marshes by gathering short term and longer-term data on the erosion/accretion of marsh surface sediments.
(4) Measure the aboveground production of marsh vegetation.
(5) Determine nekton (e.g. fish and macrocrustaceans) utilization of fringing marsh at the individual, population and community levels.
(6) Identify invertebrate assemblages associated with the vegetated marsh surface and measure secondary production.
(7) Determine the plant diversity at each site, including plant species richness and relative abundance.

**Table 1. Functions and values of New England’s salt marshes (from Morgan and Short 2000).**

| Function | Value |
|---|---|
| Primary production | Support estuarine and offshore food webs |
| Nutrient regeneration and recycling | Support estuarine and offshore food webs |
| Production export | Support estuarine and offshore food webs |
| Soil organic matter accumulation | Support estuarine and offshore food webs<br>Counter effects of sea level rise |
| Maintenance of plant communities | Provide habitat for animals,<br>Provide high biodiversity |
| Maintenance of animal communities | Support shellfish, finfish production,<br>Provide high biodiversity |
| Provision of habitat for fish, birds (as nesting, foraging and/or nursery areas) | Support of finfish production,<br>Recreational resources (hunting, observation, photography) |
| Nutrient and contaminant filtration | Improve water quality |
| Sediment filtration and trapping | Counter effects of sea level rise,<br>Improve water quality |
| Dissipation of physical forces (of waves, currents and ice) | Protect upland from erosion,<br>Reduce flood-related damage |
| Maintenance of self-sustaining system | Recreation, Aesthetics, Open space,<br>Landscape level biodiversity,<br>Historical value, Education |

# METHODS

## Study Site Selection

During the fall of 2001, we conducted reconnaissance via boat of the Casco Bay shoreline from the mouth of the Fore River to Little John Island. Nine fringing salt marshes were then selected from the initial pool of 32 sites (Figure 1). The Fore River and its tributaries were excluded due to recent impacts from oil spill events, including the Julie N spill in 1996. After a preliminary survey, each of the 32 sites was assigned to a high, intermediate or low impact level, based on the level of apparent human alteration to the adjacent upland landscape, including the presence of lawns, impervious surface, invasive plants, surface water runoff, and restrictions to tidal flow. Ten sites were eliminated due to inadequate access. From the remaining sites (equally divided among the three impact levels), three were randomly selected from each of the impact groups for study, resulting in a total of nine sites.

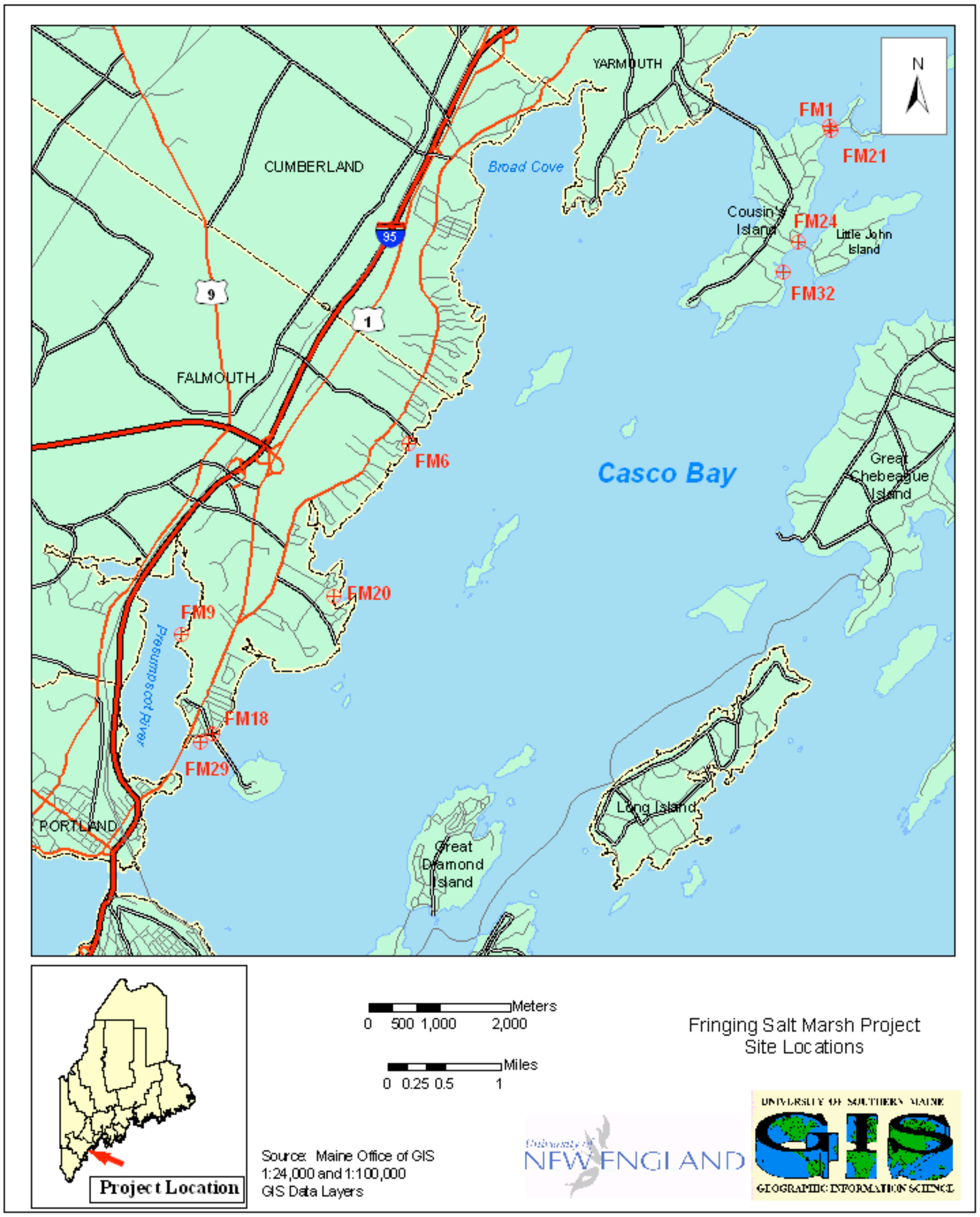
## Study Site Mapping

The study site boundaries were delineated in the field using a Geo Explorer GPS receiver (Figure 2). The GPS unit was WAAS (Wide Area Augmentation System) enabled. All data points were also post processed (differentially corrected). By following Trimble Protocol for collection and correction of the data a sub-meter horizontal accuracy was achieved. This accuracy rating is based solely on Trimble Standards and was not field verified. Three distinct habitat types were delineated: High marsh, low marsh, and non-marsh intertidal. Generally, this last habitat type was simply sandy or gravel beach areas with no vegetation that fell within the intertidal range and within the site boundary. Site and marsh community boundaries were then converted to polygons and area calculations made. Fringing marsh site boundary maps were overlaid onto Maine Office of GIS CITIPIX ortho-rectified digital images (1:24,000 scale) (April 2001).

## Physical characteristics of fringing marsh sites

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, surface slope, plant diversity, aboveground biomass and sediment deposition.

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. The nine stratified random sample points were used for year 1



Fringing Salt Marsh Project
Site Locations

Source: Maine Office of GIS
1:24,000 and 1:100,000
GIS Data Layers

**Figure 1. Locations of nine fringing salt marshes studied in Casco Bay, ME. Study sites are indicated by the prefix "FM."**

Figure 2. Mapping fringing salt marsh site with GPS.

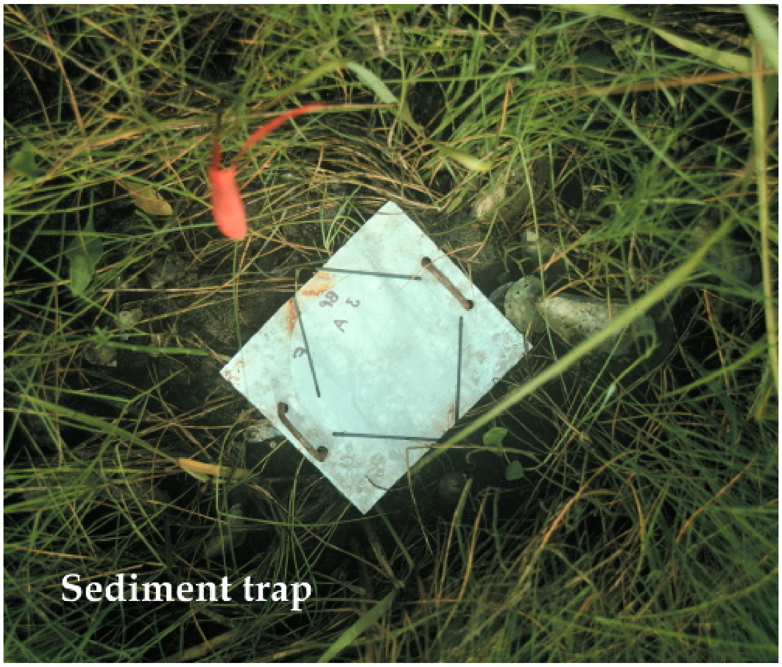


Figure 3. Sediment trap used to collect deposited sediment on fringing marsh sites.

(2002) sampling. In year two (2003), all sample points were shifted two meters along the horizontal access of the marsh.

### *Marsh width*

The width of each marsh site was determined by measuring the distance from the upland edge to the water's edge of the marsh at nine randomly spaced intervals. Means and standard errors for the nine data points sampled at each site were calculated and compared with ANOVA. Pairwise comparisons were then made using Student-Newman-Keuls.

### *Marsh surface slope*

The surface slope was measured at each sample point in a direction perpendicular to the water's edge using Topcon laser survey equipment. The difference in elevation (rise) between two points approximately one meter apart was determined by placing the survey equipment on both the points and then subtracting the values. Means and standard errors for the nine data points sampled at each site were calculated and compared with ANOVA.

### *Fetch*

Fetch was determined at each site by measuring the distance from the marsh edge to the nearest land across the water in three directions: perpendicular to the marsh edge, 45° to the right and 45° to the left.

### *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. To determine the height of the relative benchmarks and to rectify the data to a known vertical datum (NAVD88), a survey of the relative benchmarks was conducted using Trimble 5700 series receivers. The survey consisted of a combination of Static Occupation and Kinematic Survey methods. Accuracy based on Trimble Unit Specifications is +- 5mm horizontal and +- 5mm vertical for Static Occupation Survey method and +-10mm horizontal and +- 20mm vertical for Kinematic Survey method.

After the elevations of the nine sample points on each marsh were determined, means and standard errors were calculated and these site means were compared with ANOVA.

### *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 during both years of the study.

Means and standard errors for the nine data points sampled at each site were calculated. These means were then compared from site to site with Analysis of Covariance (ANCOVA), using month as a covariate. Pairwise comparisons were made using Scheffe's S test.

## Sediment trapping

### *Short-term measurements*

Sediment Traps

The amount of sediment accumulated on sediment traps (discs) over a two-week period was measured in June and July during each year of the study. The sediment traps were designed after those of Reed (1989), and consisted of a pre-weighed mylar disc (8cm diameter) attached to a piece of sheet metal with plastic coated clips and held onto the marsh surface by two 6 inch long metal sod staples (Figure 3). Sediment traps were distributed on the marsh surface at each of the nine stratified random sample points for each site. Mylar discs were collected after two weeks, dried at 60C for 48 hr and weighed.

Means and standard errors for the nine data points at each site were calculated. After square root transforming the data, site means were compared with Analysis of Covariance (ANCOVA), using year as a covariate. Pairwise comparisons were also made.

Suspended Sediment

To determine the amount of suspended sediment in the water coming onto the marsh surface at high tide, water was collected at three points just seaward of the marsh edge. Four 250 ml plastic bottles were attached to each of three stakes, which were hammered into the sediment just seaward of the marsh grass so that the base of the first bottle was at ground level and the base of the second bottle was just above the mouth of the first, etc. Water was collected from all sites on the same spring tide night. The concentration of sediment in the water column was determined by filtering the samples through pre-weighed 0.45 $\mu$m glass fiber filters, then drying the filters and sediment at 60C for 48 hours.

Means of the three sampling locations were calculated for each site, and then these means were compared with ANCOVA, using year as a covariate. Site means were then compared using Student-Newman-Keuls.

### *Longer-term measurements - Marker horizons of feldspar*

Marker horizons of feldspar or brick dust (Cahoon and Turner 1989) were placed at four of the nine stratified random sampling points described above at each site in June of the first year and recovered during August of the second year. The location for the marker horizon was determined by measuring three meters from the sampling points (described above) away from the marsh zero point. A 1/4m$^2$ quadrat was laid on the marsh surface, and 500 ml of feldspar was dispersed throughout the area. Each quadrat was then marked with a 10-inch long PVC pipe in the lower right-hand corner and a metal spike in the center. The marker horizons were found 14 months later by locating the nails with a metal detector. Three cores were taken at each sampling point and if a marker horizon was detected, the amount of sediment deposited above the horizon was measured with calipers. Values were averaged and standard errors calculated for low marsh and high marsh sampling points at each site.

## Plant diversity

The species richness and relative abundance of each of the higher plants were assessed once at each site, in July of 2002. The point intercept method (Roman and James-Pirri 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 4). In addition, plants observed on the marsh that did not fall into the sample quadrats were noted.

Data collected from sample quadrats were summarized to determine the mean percent cover for each plant species sampled on the marsh. In addition, the percent cover values for all high marsh species were summed, and this value was compared to the percent cover of *Spartina alterniflora* (the predominant low marsh species) at each site. 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). After quadrat sampling was complete, transects were walked along 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.

## Aboveground production of marsh vegetation

Primary production of vascular plants at each site was evaluated by measuring the annual standing crop (the live aboveground plant biomass) at the end of July during the first year and at the end of August the second year. Samples were collected from each marsh site at the nine stratified random points described above. All vegetation in a 0.25m$^2$ quadrat at each sample point was clipped. Live plants were separated from dead material and all the species were separated and stems counted before samples were dried at 60C for 48 hr and weighed.

Means and standard errors for the nine data points at each site (each year) were calculated. Overall site means for 2002 and 2003 were then square root transformed and

Figure 4. Using the point-intercept method (Roman et al. 2001) to determine percent cover of plant species.

Figure 5. a) A fyke net deployed at a fringing marsh site 1 on Cousins Island. b) Retrieving a sample from fringing marsh site 24 on Cousins Island.

compared with ANCOVA, using year as a covariate, and Scheffe's S test. In addition, the ratio of live aboveground biomass to dead aboveground biomass was calculated.

Stem densities of *Spartina alterniflora* stems in each clipped plot were calculated, and then site means were determined using only data from quadrats containing solely *S. alterniflora*. These means were compared with ANCOVA, with year as a covariate.

## Invertebrates

Benthic macroinvertebrates were sampled from three randomly selected points in the low and high marsh areas as well as in *Phragmites*- and *Typha*-dominated areas (if present) using a 7.8 cm internal diameter corer (Merrit et al. 1984, Turner and Trexler 1997). Samples were collected in June, July and August of 2002. All organisms greater than 0.5mm in size in the top four cm of each core were counted and identified in the lab. Samples were first fixed in 10% formalin and then preserved in a mixture of 70% ethanol and Rose Bengal stain (for the purpose of easy separation from the substrate). After separating invertebrates from the core samples, individuals were keyed to the lowest taxonomic level possible. Lengths of the organisms as well as widths of prostomiums or head capsules were measured to determine size class and biomass. 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 in the months of June, July and August. These means values for the three months were then averaged to get an average monthly number of individuals for each invertebrate taxa identified.

## Nekton (fish and macrocrustaceans)

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, during the weeks of 24 June, 23 July, 12 August, and 9 September, 2002, and during the weeks of 16 June and 11 August in 2003. Up to fourteen people participated in sampling during each sampling week. All nine sites were sampled within a 3-4 day time frame during each sampling period. Net openings were 1.2 $m^2$ opening with two 15m long wings. The net opening was 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. Nets were deployed at six sites during the day at low tide, with the opening to the net placed at the lower limit of low marsh vegetation (Figure 5). 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 furled with a reefing knot. When the incoming tide had reached its furthest extent, the tide line above the net was flagged, and the wings released so the float lines popped to the surface, and the net fished the outgoing tide. Fish were collected from the cod end 3 to 5 hours later, once the tide had receded below the level of the first fyke. 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 reefed and the process was repeated during the night tide. The nets were then moved to the six remaining sites and the process was repeated.

All fish and crustaceans were counted and identified to species, 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 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. Metrics 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). Here we present metrics based on biomass rather than number, as biomass includes information about body size. 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. Occasionally a school of fish would be captured, skewing the biomass density for that sample. In these cases we present the original data, but also present the “adjusted” data, for which the biomass value for the school of fish is replaced by the highest non-schooling biomass density for that species at any site sampled during the same tide.

For each site we calculated each metric for each fyke net sample collected for each sampling period, one value for the day-tide sample, and one value for the night-tide sample (complete data sets included in Data Appendix CD). This generated eight values (n=8) for each metric at each site in 2002, and 4 values (n=4) for each metric at each of site in 2003. Means and standard errors were calculated for each metric for each site and are presented as bar graphs. At this point in time we have not performed statistical analyses to test specific hypotheses. In the future, we plan to use multivariate techniques to identify relationships between nekton parameters and parameters describing vegetation, invertebrates, geomorphology and geographic setting at each site.

# RESULTS

## Study Site Mapping

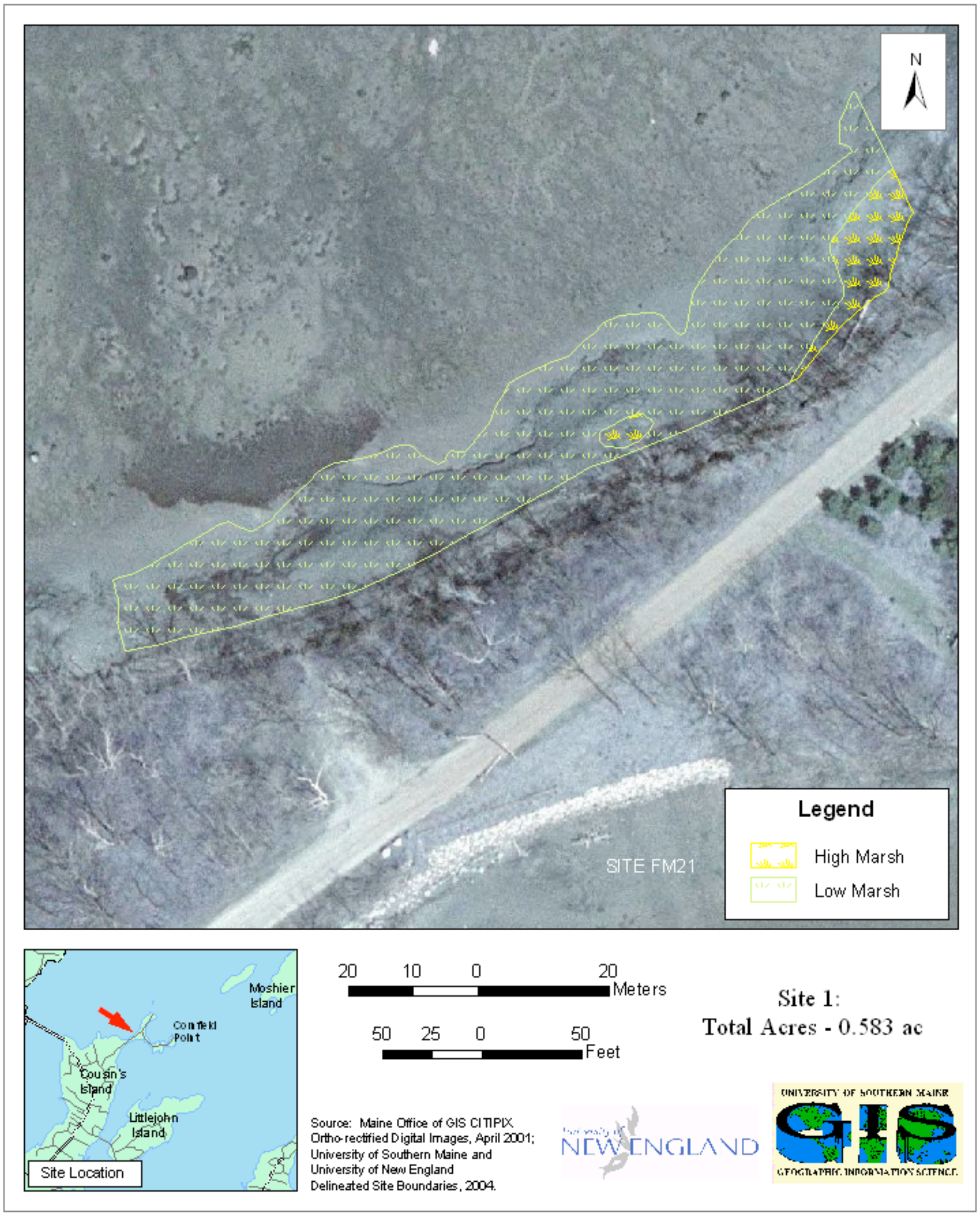
Study site boundaries are shown in Figures 6-14. Note that in some cases (see for example sites 18, 21, 24 ) the fringing marsh extended farther along the coast than the actual study site. High marsh, low marsh and non-marsh intertidal areas that were calculated from polygons are listed for each site in Table 2. Marshes ranged in size from just over a quarter of an acre to almost two acres. In addition, the original percent low marsh and high marsh areas for each site that were estimated from simple field measurements (see Methods – Location of Sample Points) are included for comparison. All marsh sites included both high and low marsh plant communities.

## Physical characteristics of fringing marsh sites

### *Marsh width, surface slope, fetch, elevation and salinity*

The widths of the fringing marsh sites ranged from 9 m to 67 m, and many of these means were significantly different from each other (Figure 15a). Marsh surface slope also varied widely from site to site, although these differences were not significant (Figure 15b). High and low values ranged from a relatively flat 1% slope at site 32, to a steeper 13% slope at site 9. Fetch, measured as the distance from the seaward marsh edge to the nearest land, varied widely as well. In addition, individual sites often had a relatively short fetch in one direction but a long fetch in another (Figure 15c). The elevations of sample points were determined for both 2002 and 2003, as sample points were shifted two meters down the marsh in the second year. The mean elevations for each site are shown in Figure 15d. Sites 1 and 21, which had the greatest proportion of low marsh, also had the lowest mean elevations. Analysis of covariance showed a significant difference in the mean elevations of the nine sites (year $p = 0.7711$, site $p = 0.0006$). Using the Student-Neuman Keuls pairwise comparison, differences between individual sites were detected. These differences are illustrated in Figure 15d. Note that the accuracies of the elevation benchmarks as based on Trimble Unit Specifications are +- 5mm vertical for the Static Occupation Survey Method (used at sites 6, 9, 20, 21, 29, 32) and +-10mm horizontal and +- 20mm vertical for the Kinematic Survey Method (sites 1, 18, 24).

The average annual soil water salinity of sites, determined from porewater extracted from marsh sediment in June, July and August, was consistent from 2002 to 2003 (Figure 16). However there were significant differences in the average soil water salinity from site to site, with site 6 having the lowest values (13 ppt) and site 21 having the highest (36 ppt) (ANCOVA, $p = 0.0001$, month $p = 0.0001$).

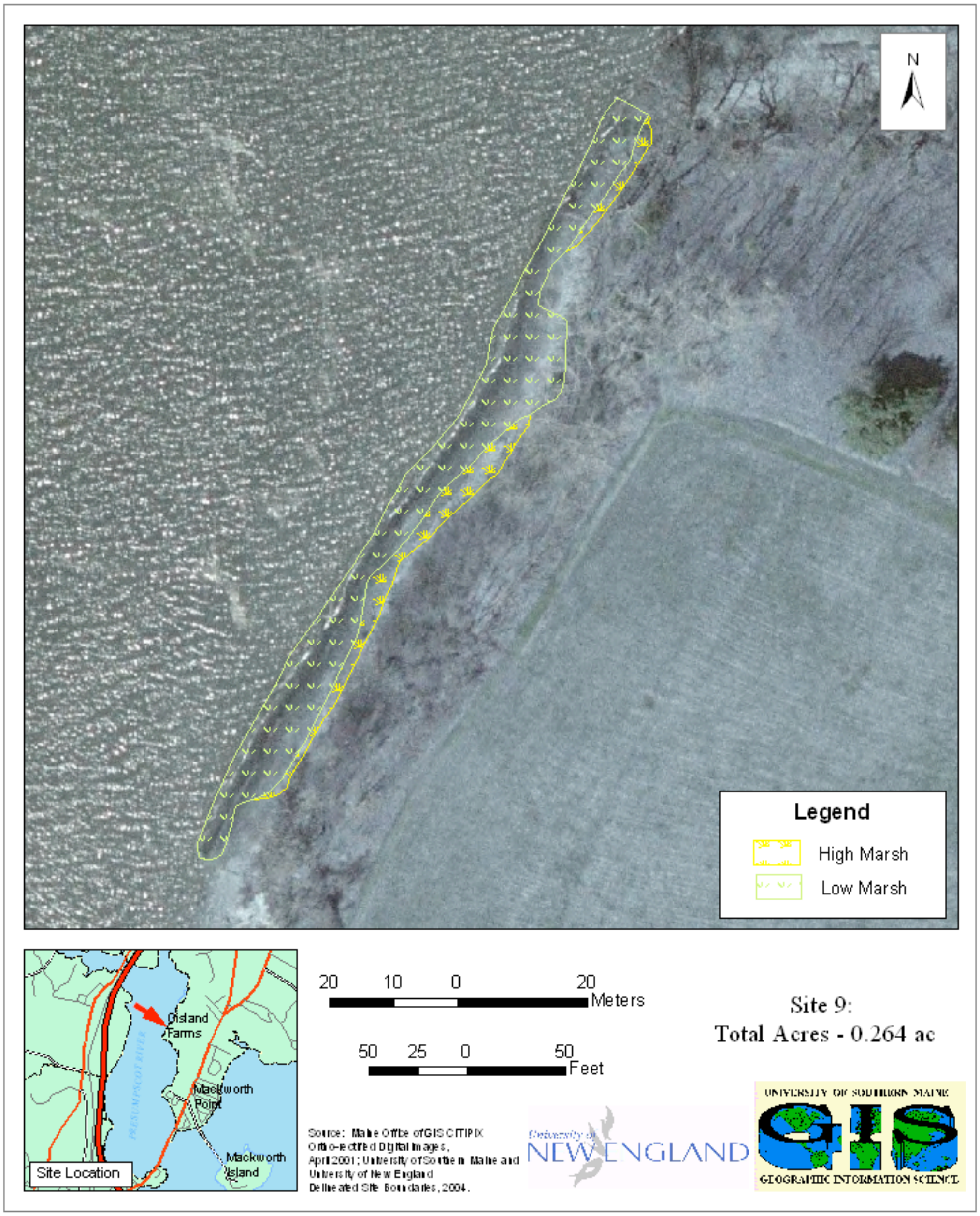


Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

Figure 6. Site 1, Northwest of Sea Meadows Lane, Cousins Island, Yarmouth.

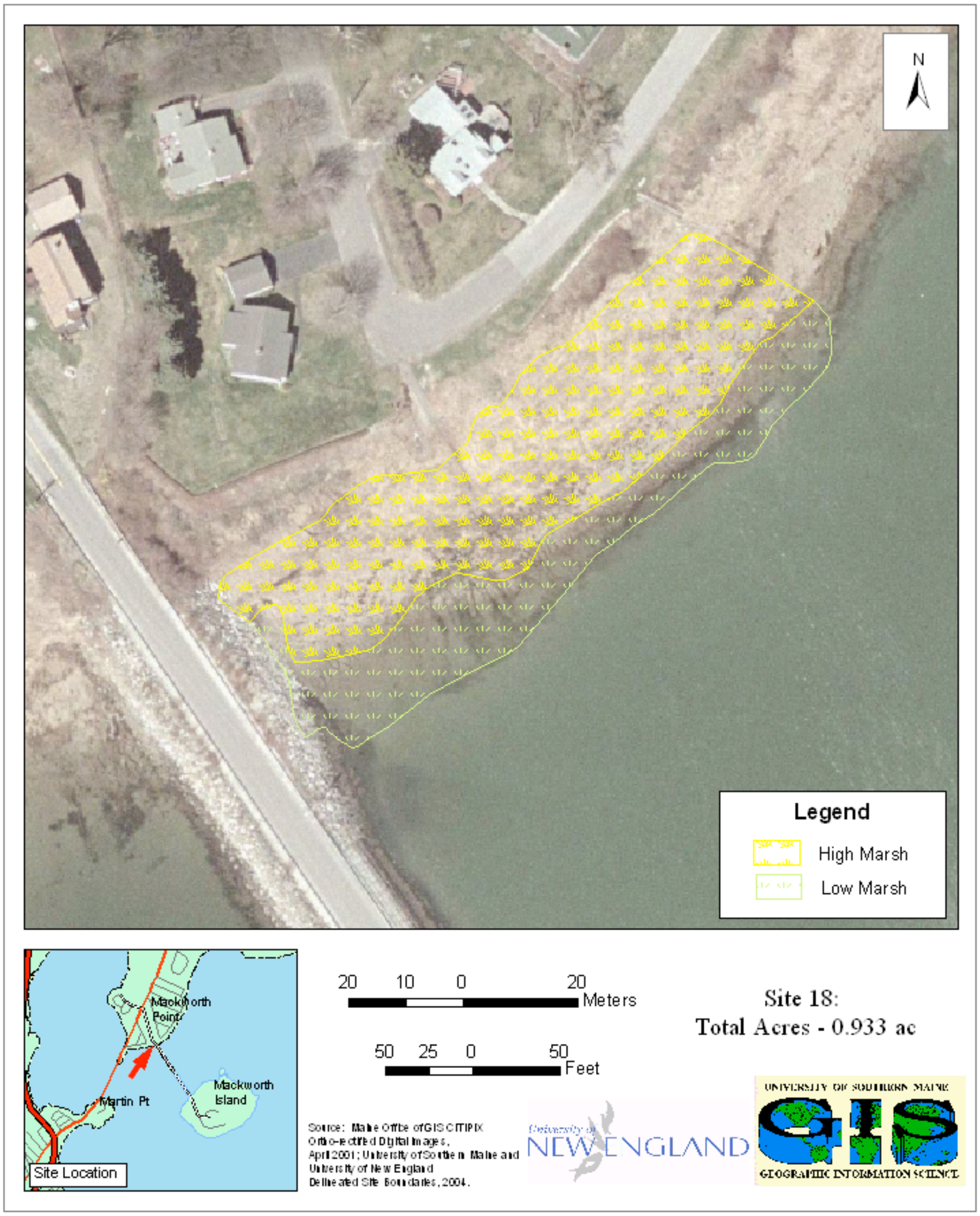
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 7. Site 6, south of Town Landing, Falmouth Foreside.**



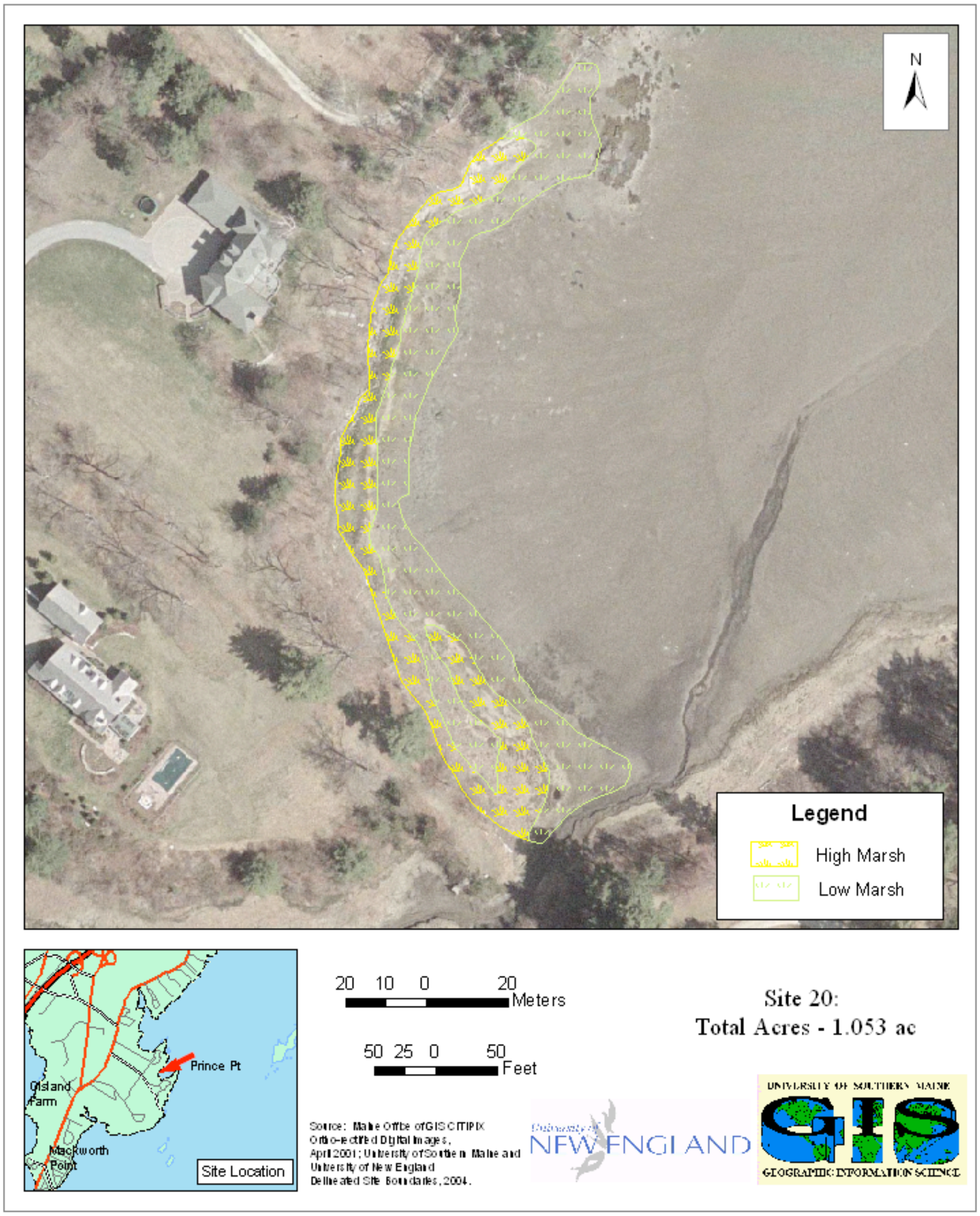
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 8. Site 9, Maine Audubon Society, Gilsand Farm, Falmouth.**



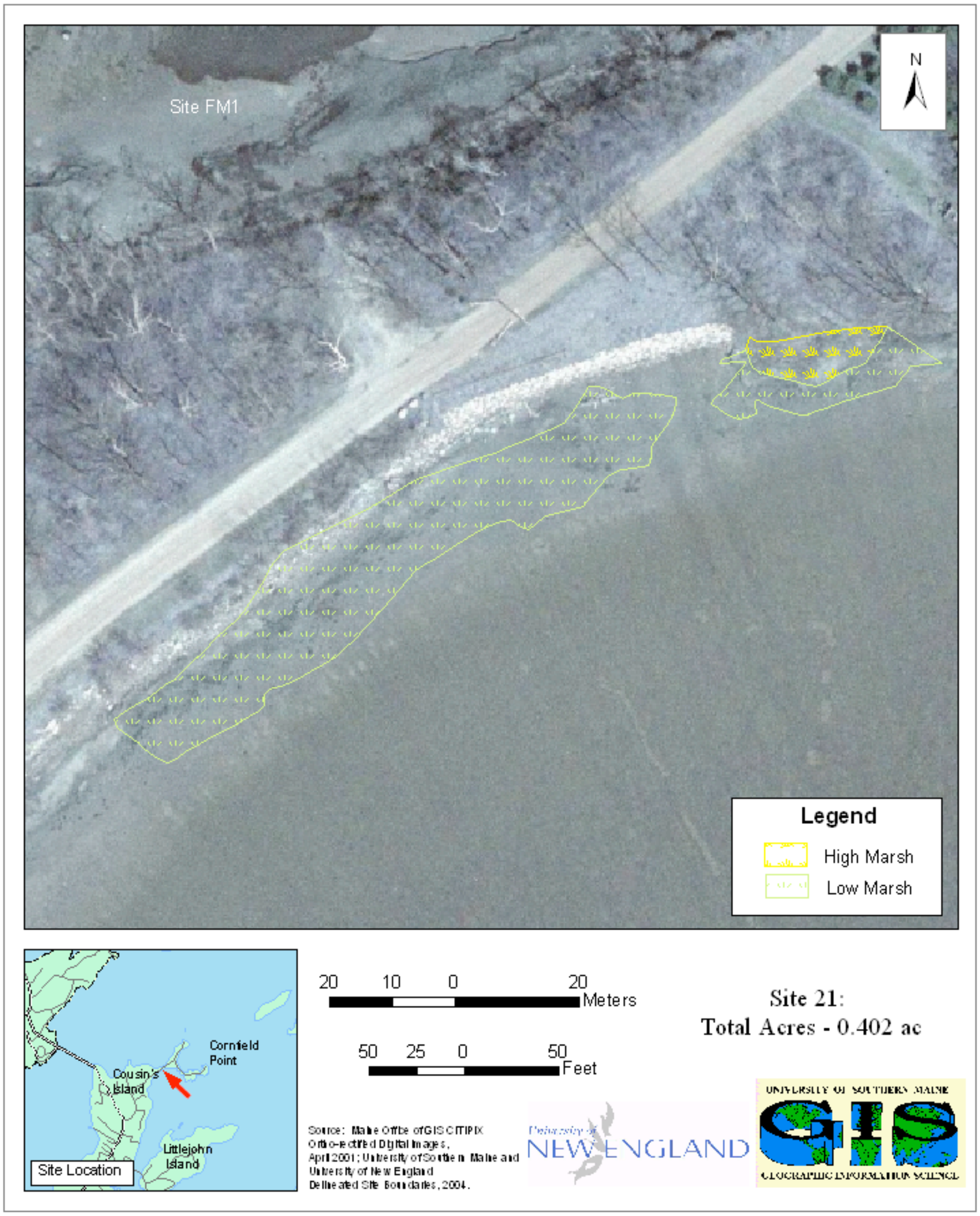
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 9. Site 18, Shoreline Road, Falmouth.**



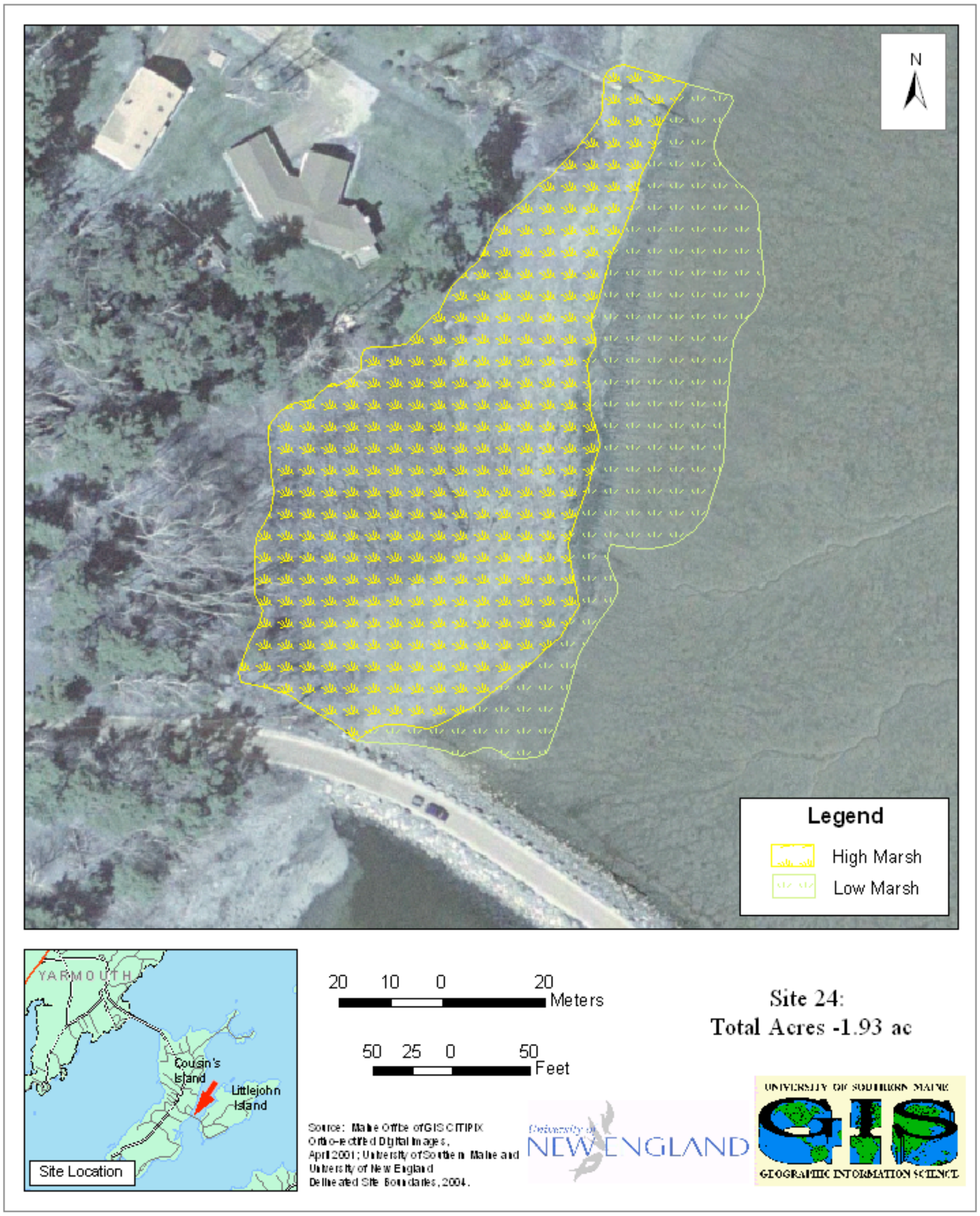
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 10. Site 20, Bartlett Point, Yarmouth.**



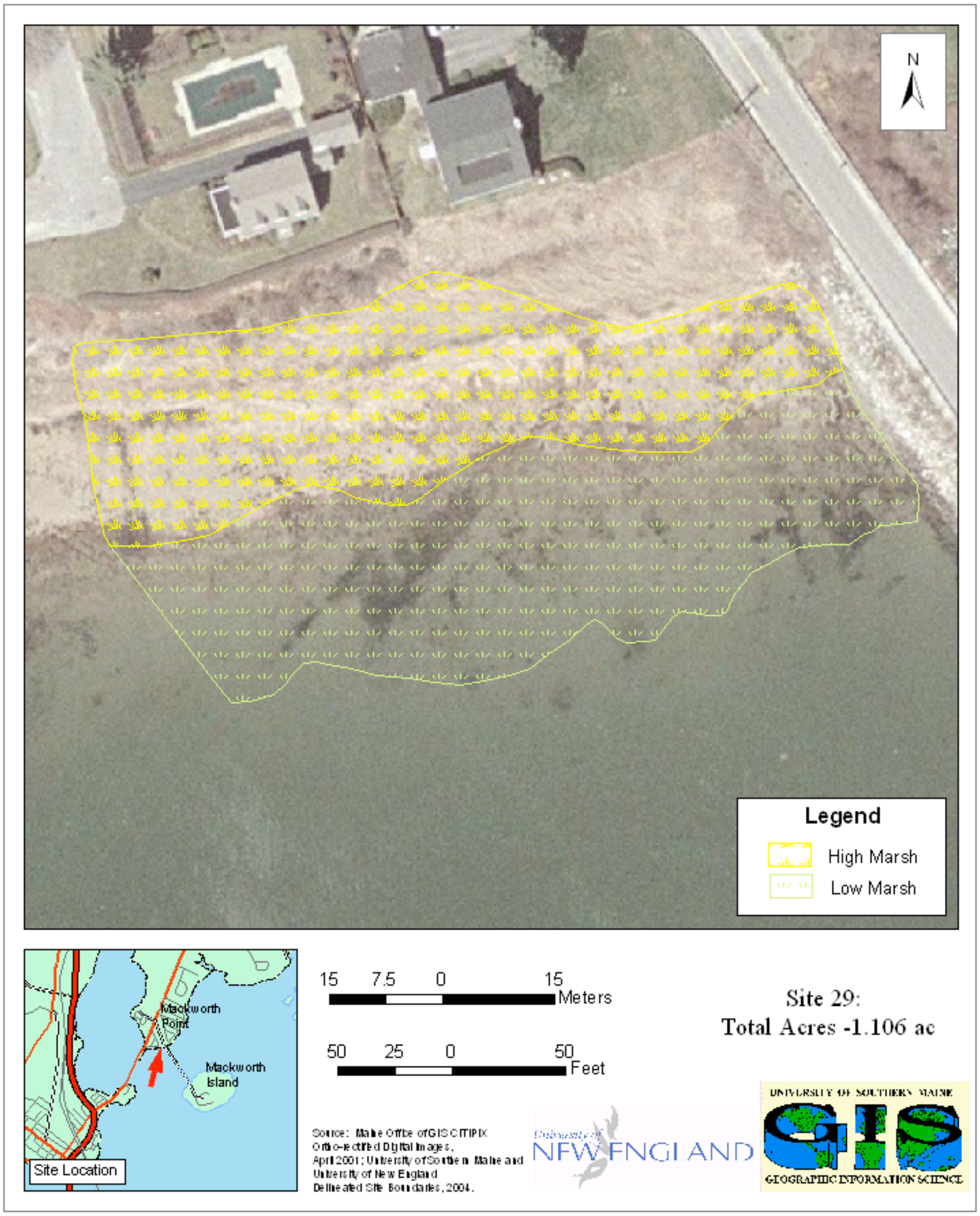
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

Figure 11. Site 21, South of Sea Meadows Lane, Cousins Island, Yarmouth.



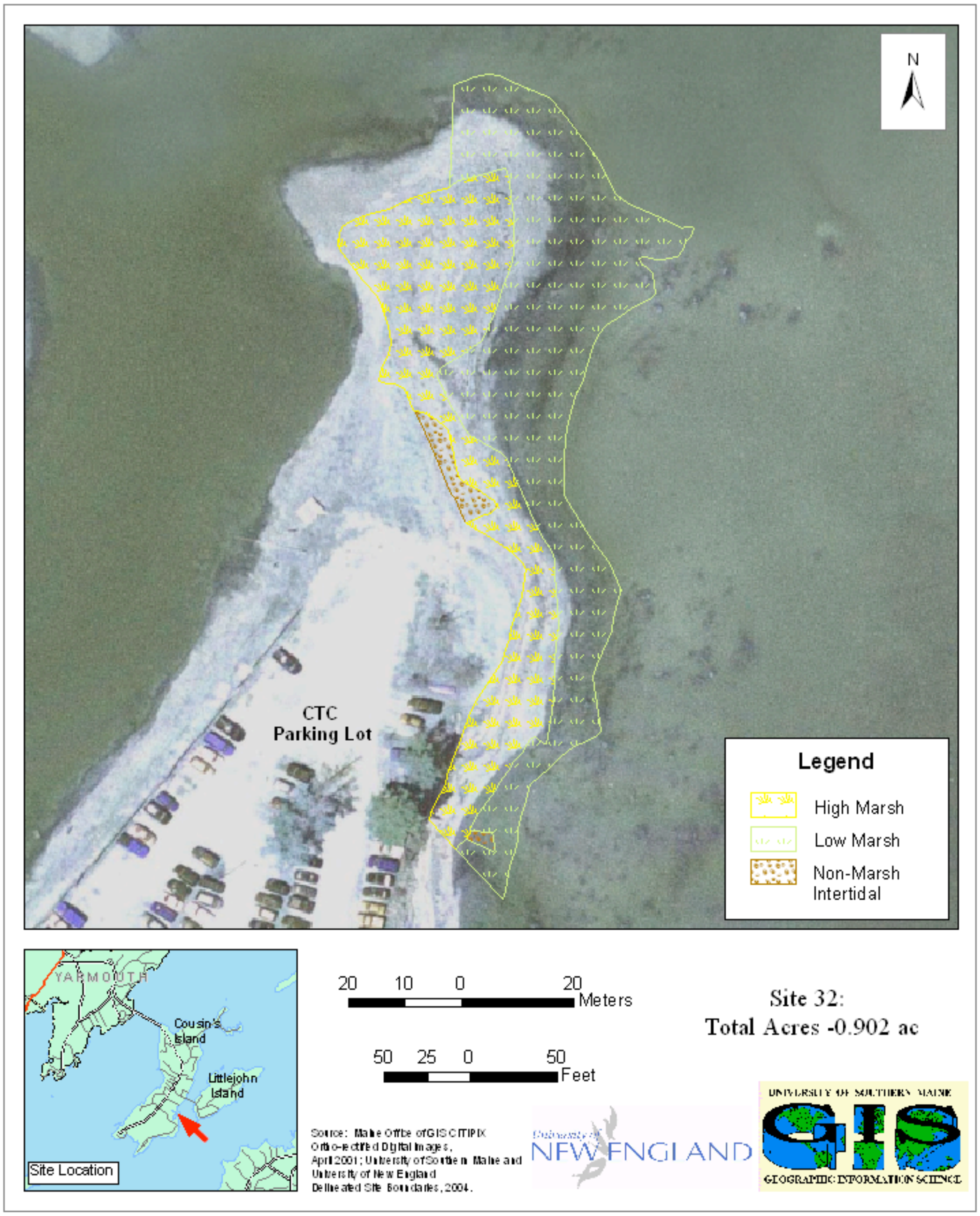
Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 12. Site 24, Northwest of Littlejohn Island Bridge, Yarmouth.**



Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

**Figure 13. Site 29, Bayshore Road, Falmouth.**



Source: Maine Office of GIS CITIPIX Ortho-rectified Digital Images, April 2001; University of Southern Maine and University of New England Delineated Site Boundaries, 2004.

Figure 14. Site 32, CTC Parking Lot, Cousins Island, Yarmouth.

Table 2. Results of GPS/GIS mapping of fringing marsh sample sites, including area and percent of low and high marsh communities. Preliminary estimates of percent high and low marsh for each site as determined by field measurements with a meter tape are also listed.

| | | **GPS/GIS Results** | | | | | **Preliminary Results** | |
|---|---|---|---|---|---|---|---|---|
| Site | Type | Area (m2) | Acres | Sum of Site | % High | % Low | % High | % Low |
| 1 | High | 180 | 0.0512 | | | | | |
| | Low | 2160 | 0.5318 | 0.583 | 9 | 91 | 5 | 95 |
| 6 | High | 982 | 0.2419 | | | | | |
| | Low | 2796 | 0.6885 | 0.930 | 26 | 74 | 24 | 76 |
| 9 | High | 33 | 0.0475 | | | | | |
| | Low | 879 | 0.2164 | 0.264 | 18 | 82 | 28 | 72 |
| 18 | High | 2512 | 0.6185 | | | | | |
| | Low | 1277 | 0.3144 | 0.933 | 66 | 34 | 69 | 31 |
| 20 | High | 1710 | 0.4211 | | | | | |
| | Low | 2566 | 0.6319 | 1.053 | 40 | 60 | 59 | 41 |
| 21 | High | 134 | 0.0330 | | | | | |
| | Low | 1304 | 0.3691 | 0.402 | 8 | 92 | 15 | 85 |
| 24 | High | 5244 | 1.2914 | | | | | |
| | Low | 2585 | 0.6365 | 1.928 | 67 | 33 | 68 | 32 |
| 29 | High | 2152 | 0.5300 | | | | | |
| | Low | 2338 | 0.5758 | 1.106 | 48 | 52 | 49 | 51 |
| 32 | High | 1460 | 0.3596 | | | | | |
| | Low | 2115 | 0.5207 | | | | | |
| | Non-marsh | 75 | 0.0212 | 0.902 | 40 | 58 | 27 | 73 |

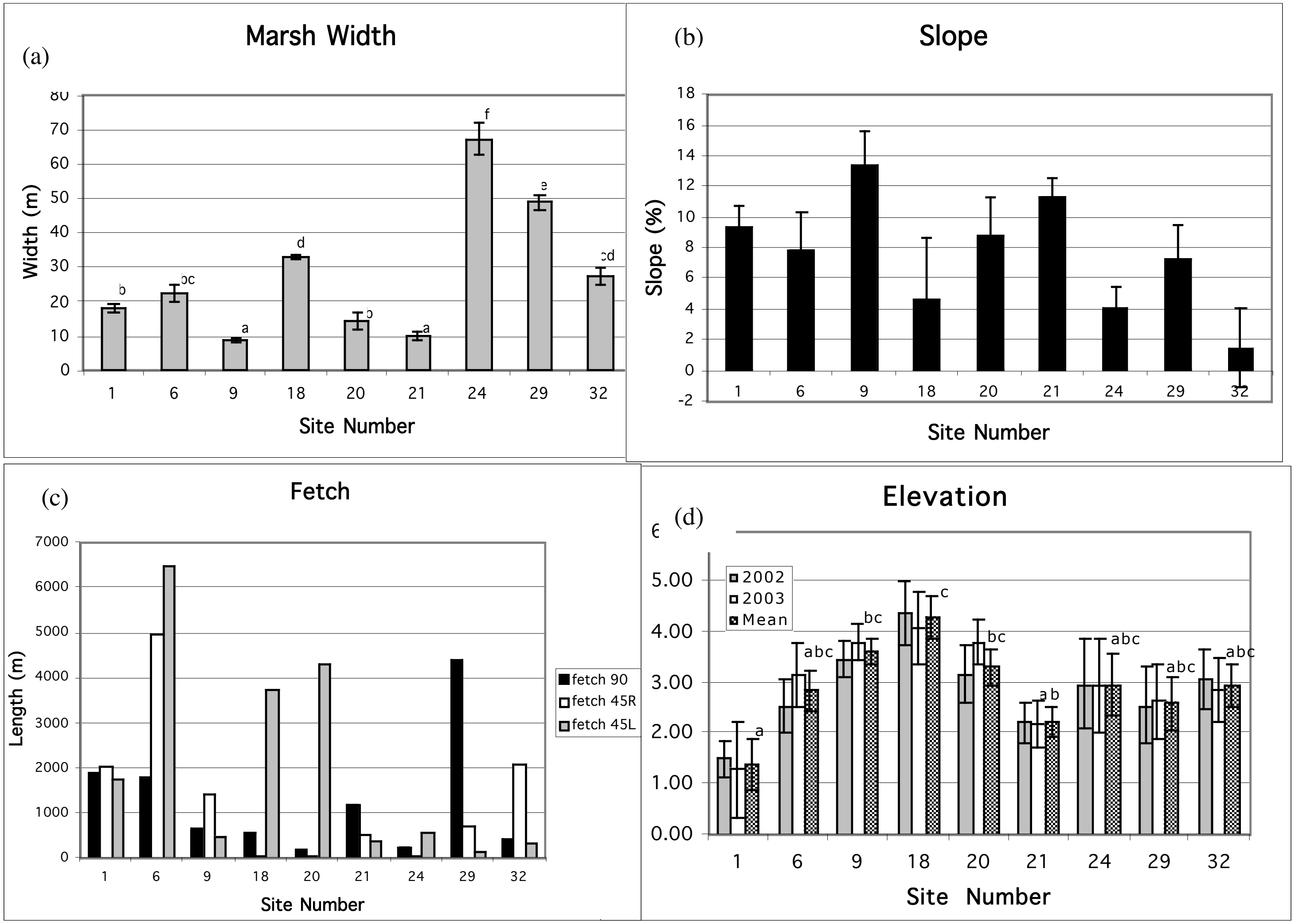


**Figure 15. Physical characteristics of fringing marsh sites. Columns with ± 1 standard error bars represent means of the nine sample points at each site. Site means followed by the same letter are not significantly different from each other (Width ANOVA p = 0.0001, Student-Neuman Keuls (SNK) p = 0.05; Elevation ANCOVA year p = 0.7711, site p = 0.0006, SNK p = 0.05).**

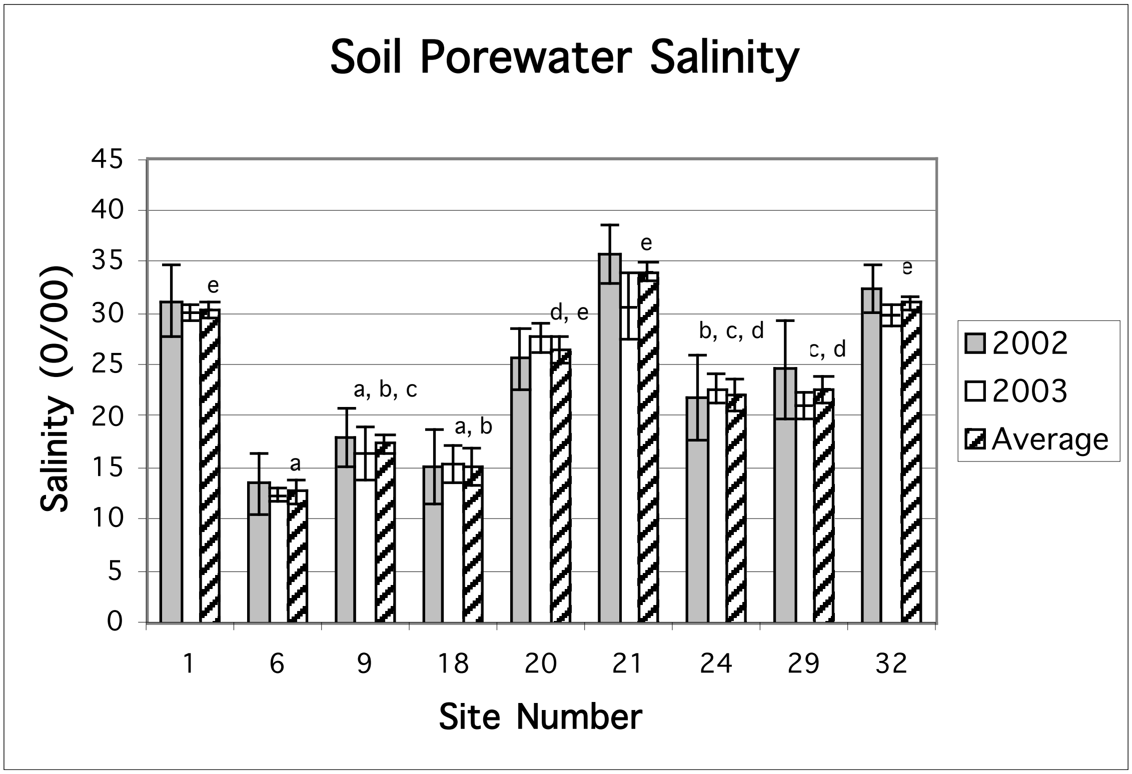


**Figure 16. Average annual soil water salinity of sites, determined from porewater extracted from marsh sediment in June, July and August of each year. Bars are means ± 1 standard error. Bars representing overall averages followed by the same letter are not significantly different from one another (ANOVA, p=0.001, Scheffe's S, p=0.01).**

## Sediment trapping

### *Short-term measurements*

*Sediment traps*

The amount of sediment deposited on the marsh surface over two week periods in June and July is illustrated in Figure 17. Figure 17a includes all values collected, whereas Figure 17b summarizes the data without extremely high numbers (>100 g/m$^2$/day). In all cases, it is clear that sediment was being deposited on the marsh surfaces.

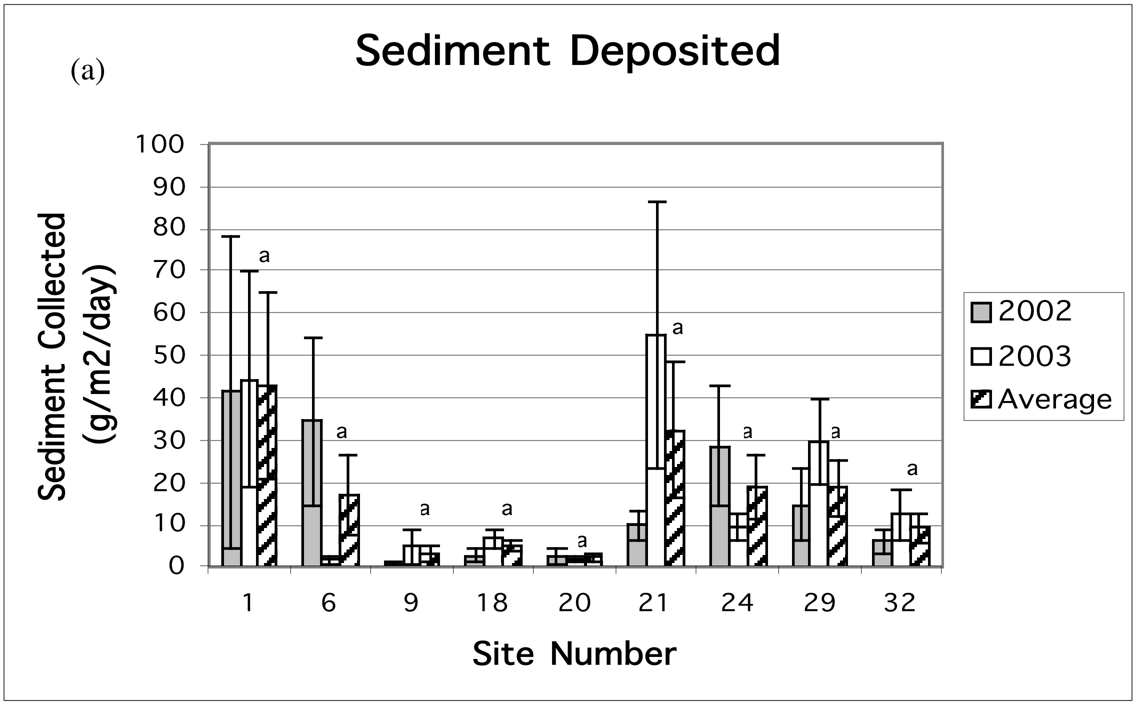
A significant difference in the amount of sediment deposited was evident between site means when large values were included in the analysis (ANCOVA, square root transformed data, p = 0.0102, year p = 0.6374), but a pairwise comparison using Scheffe's S test revealed no significant differences between paired sites (p = 0.05). When the large outlying values were removed, some differences between marshes became evident (ANCOVA, square root transformed data, p = 0.0094, year p = 0.4277). Sites 9 and 20 had significantly less sediment deposited than site 21. The remaining sites were not significantly different from each other (Games-Howell, p = 0.05).

*Suspended sediment*

The concentration of sediments in the water just seaward of each site was also analyzed, as the suspended sediment load might affect the amount of sediment being deposited on the marsh surface. Figure 18 shows the mean values for suspended sediment at each site for 2002 and 2003. Values averaged over two years were significantly different for some sites (ANCOVA, square root transformed data, p = 0.0026, year p = 0.0014). For example, site 24 values (0.5 g/l) were five times as great as values for site 32 (0.1 g/l) (Student-Newman-Keuls p = 0.01). However, in this study there were no correlations between the amount of suspended sediment in the water coming on to the marsh sites and the amount of sediment deposited on the sediment traps in any trial. (Correlation coefficients ranged from –0.484 to 0.083.)

### *Longer-term measurements - Marker horizons of feldspar*

After 14 months, the amount of sediment accumulated over marker horizons in both the low and high marsh zones was measured. Markers at sites 1, 21 and 24 (high marsh) could not be recovered. Metal spikes and PVC pipes that had been used to identify the locations of the marker horizons could not be located, most likely because ice had pulled them out. In addition, at several of the low marsh locations, the spikes were still present, but no marker horizon could be found. This could be due to erosion of surface sediments (including the marker horizon), or because the marker horizon was washed away by the incoming tide just after it was laid down. For the marker horizons we did locate, the mean depth of sediment accumulated above the marker ranged from 0.37 cm at site 24 (low marsh) to 0.74 cm at site 18 (high marsh) (Figure 19). No difference in the depth of



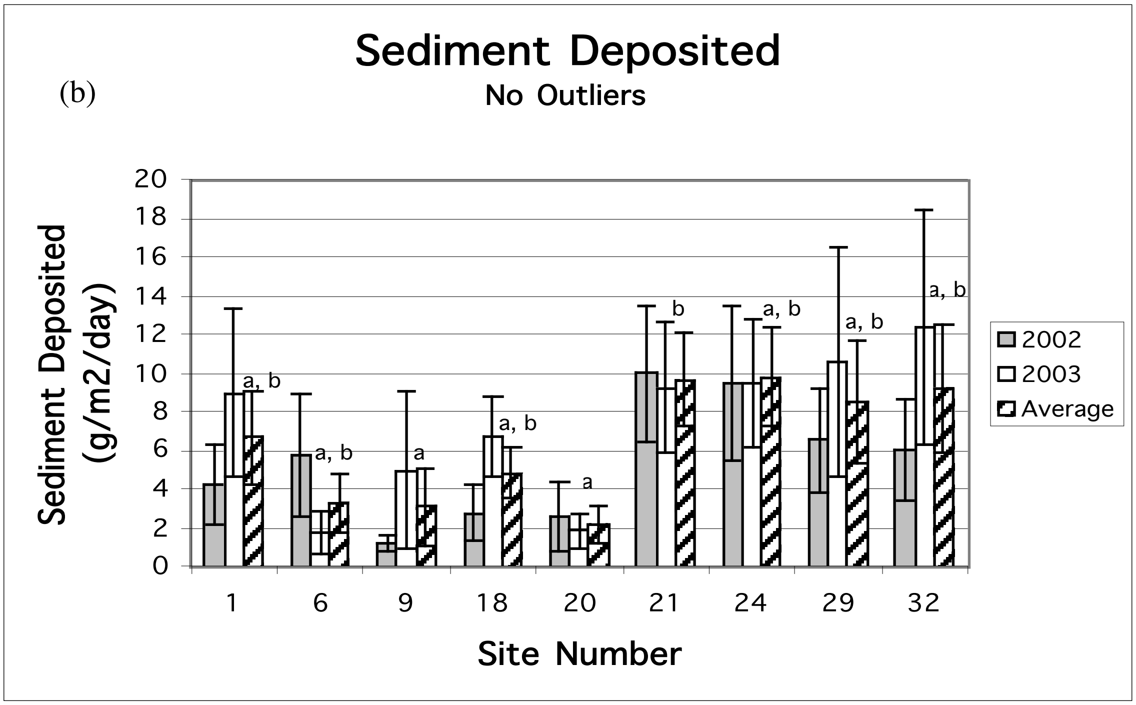


**Figure 17. Amount of sediment deposited on fringing marsh sites. Error bars are ± 1 standard error from the mean. Bars representing overall averages followed by the same letter are not significantly different from one another. a) All data included (ANCOVA, square root transformed, p=0.0102, Year p = 0.6374, Scheffe's S, p=0.05). b) Values greater than 100 excluded (ANCOVA, square root transformed, p=0.0094, Year p= .4277, Games-Howell, p=0.05).**

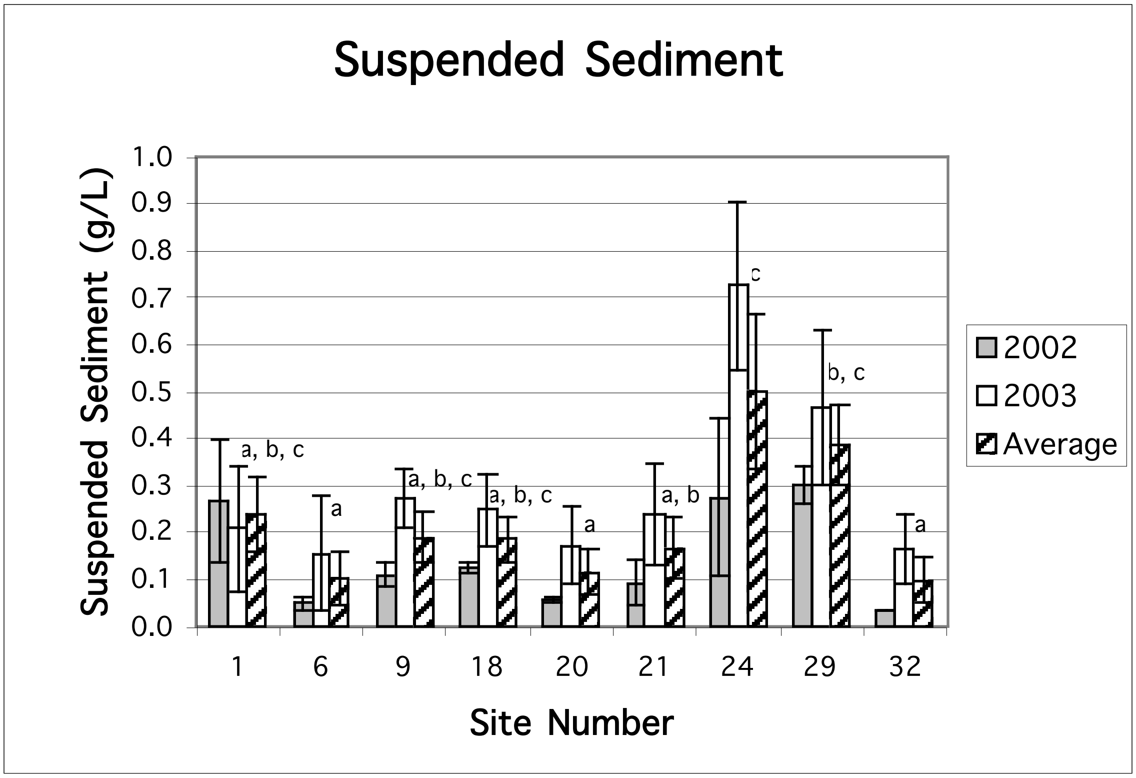


**Figure 18. Suspended sediment concentration of tidal waters coming onto fringing marsh sites. Error bars are ± 1 standard error from the mean. Bars representing overall averages followed by the same letter are not significantly different from one another (ANCOVA, square root transformed data, $p = 0.0026$, year $p = 0.0014$).**

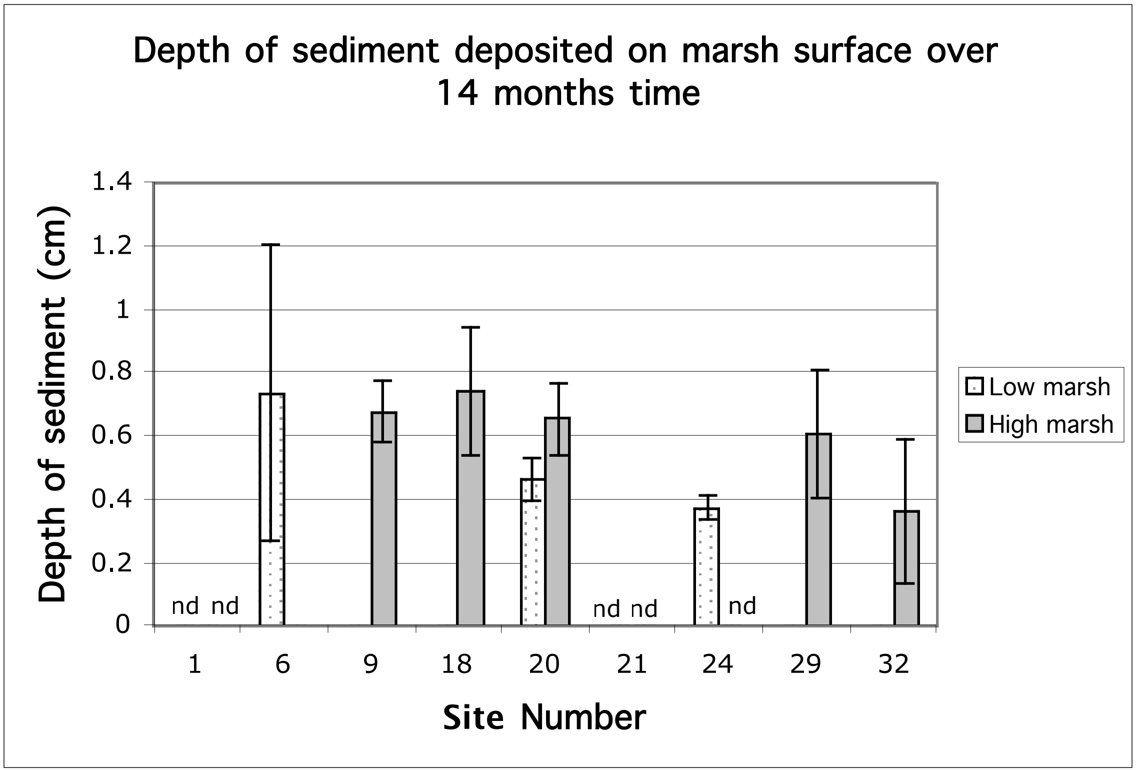


**Figure 19. Depth of sediment deposited on marsh surface over 14 months time. Error bars are ± 1 standard error from the mean.**

sediment accumulated was observed between sampling points located on the low marsh and sampling points located on the high marsh.

## Plant diversity

Table 3 lists the plant species found at all nine fringing marsh from most common to least common. On average, *Spartina alterniflora* (smooth cordgrass) was the most common species found on the nine sites, followed by *Spartina patens* (salt meadow hay) and *Juncus gerardii* (black grass).

The mean percent cover of plant species observed in the sample quadrats at each of the nine sites is illustrated in Figure 20a and listed in Table 4. The number of species sampled in quadrats at each site varied, with eleven species at site 6 and only four species at site 24 (Figure 20, Table 4). Figure 20b includes only the most common plant species observed at each site. *Spartina alterniflora* (smooth cordgrass), the dominant low marsh species, was the most common species observed at the sample sites. Percent cover values for *S. alterniflora* ranged from18 percent at site 18 to almost 80 percent at site 1. In the high marsh, *Spartina patens* (salt meadow hay) was common, occurring at seven of the nine sites. *Juncus gerardii* (black grass) was also common in the high marsh, with values ranging from six percent cover at site 6 to 29 percent cover at site 9. *Puccinellia maritima* (goose grass) occurred at sites 6 and 32, and was fairly common at site 32, where it covered 10 percent of the marsh. *Scirpus robustus* (salt marsh bulrush) was observed at sites 9, 20, and 24 in varying amounts. *Phragmites australis* (common reed), which is known to be an invasive plant species, was present at sites 18 and 29 and was relatively abundant at these sites.

Table 5 lists the diversity indices calculated, the species richness and the total number of plant species observed at each site (including plants growing outside sample quadrats). Site 1, which was predominantly low marsh, had the lowest diversity index values. Sites 20 and 24 had the highest values for H' and E, respectively, probably due to greater freshwater input to these sites.

The proportion of high marsh vegetation to low marsh vegetation calculated from percent cover values for the nine sample quadrats at each site is illustrated in Figure 21. Most sites (six out of nine) contained more low marsh than high marsh vegetation. However, all but one of the marshes sampled did have a distinct high marsh zone, with the percent cover of high marsh vegetation as high as 84% (site 20).

## Aboveground production of marsh vegetation

### *Live aboveground biomass*

Aboveground production of sites as measured by end-of-season standing crop is illustrated in Figure 22. Values for years 2002 and 2003 were fairly consistent. There were differences in production between sites, however (ANCOVA, square root

**Table 3. Mean percent cover of plant species at nine sites. Asterisks denote species observed outside of sample quadrats.**

| *Scientific name* | **Common name** | **Percent cover** |
|---|---|---|
| *Spartina alterniflora* | cordgrass | 53 |
| *Spartina patens* | salt meadow hay | 16 |
| *Juncus gerardii* | blackgrass | 8 |
| *Phragmites sp.* | common reed | 7 |
| *Salicornia europeae* | glasswort | 2 |
| *Scirpus robustus* | salt marsh bulrush | 2 |
| *Puccinellia maritima* | goose grass | 1 |
| *Limonium nashii* | sea lavender | 1 |
| *Agropyron pungens* | stiff-leaf quackgrass | 1 |
| *Atriplex patula* | marsh orach | <1 |
| *Glaux maritima* | sea milkwort | <1 |
| *Potentilla answerina* | silverweed | <1 |
| *Panicum virgatum* | switchgrass | <1 |
| *Scirpus maritimus* | salt marsh bulrush | <1 |
| *Sueda maritima* | sea blite | <1 |
| *Spergularia marina* | salt marsh sand spurry | <1 |
| *Solidago sempervirens* | goldenrod | <1 |
| *Impatiens capensis* | jewelweed | <1 |
| *Solanum dulcamara* | bittersweet nightshade | <1 |
| *Scirpus pungens* | common three square | <1 |
| *Typha latifolia* | cattail (broad-leaved) | <1 |
| *Lythrum salicaria* | purple loosestrife | * |
| *Plantago maritima* | plantain | * |
| *Spartina pectinata* | rough cordgrass | * |
| *Typha angustifolia* | cattail (narrow-leaved) | * |
| | | |
| **Algae** | | |
| *Ulva lactuca* | sea lettuce | <1 |
| *Enteromorpha sp.* | | <1 |
| *Fucus vesiculosus* | rockweed | 2 |
| *Ascophyllum nodosum* | knotted wrack | 3 |
| *Ascophyllum nodosum 'scorpiodes'* | | * |

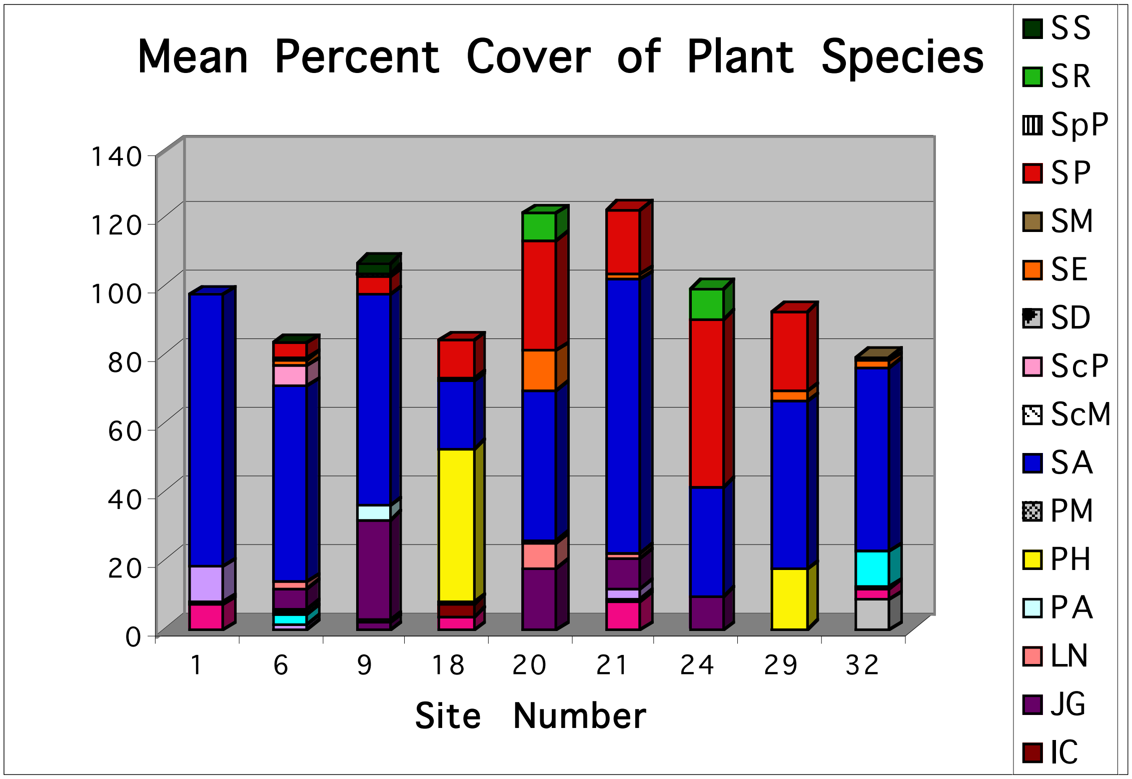


**Figure 20 (a). Percent cover of plant species sampled at each fringing marsh site. AgP=** ***Agropyron pungens*****, AN=** ***Ascophyllum nodosum,*** **AP=** ***Atriplex patula,*** **Ent=** ***Enteromorpha sp.,*** **FV=** ***Fucus vesiculosus,*** **GG=** ***Puccinellia maritima,*** **GM=** ***Glaux maritima,*** **IC=** ***Impatiens capensis*****, JG=** ***Juncus gerardii,*** **LN=** ***Limonium nashii,*** **PA=** ***Potentilla answerina,*** **PH=** ***Phragmites australis*****, PM=** ***Plantago maritima,*** **SA=** ***Spartina alterniflora,*** **ScM=** ***Scirpus maritimus,*** **ScP=** ***Scirpus pungens,*** **SD=** ***Solanum dulcamara,*** **SE=** ***Salicornia europeae,*** **SM=*****Sueda maritima*****, SP=** ***Spartina patens,*** **SpP=** ***Spartina pectinata,*** **SR=** ***Scirpus robustus,*** **SS=** ***Solidago sempervirens,*** **TL=** ***Typha latifolia.***

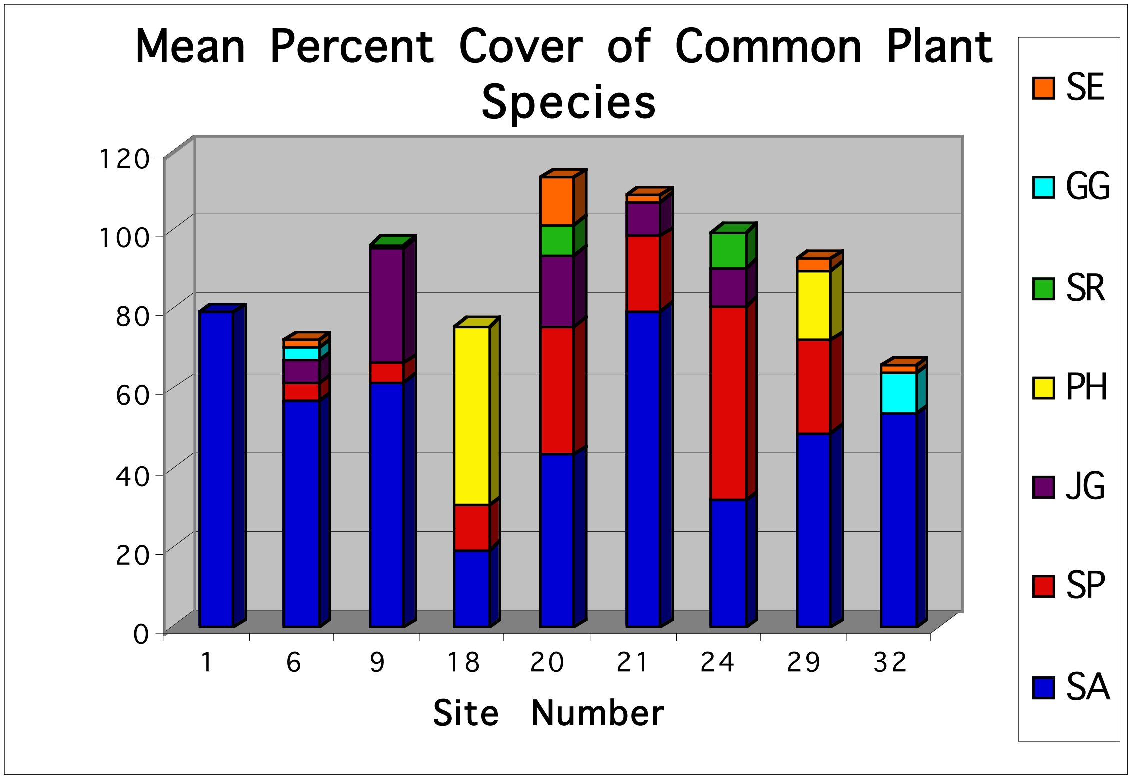


**Figure 20 (b). Percent cover of common plant species sampled at each fringing marsh site. GG= Puccinellia maritima, JG= Juncus gerardii, PH= Phragmites australis, SA= Spartina alterniflora, SE= Salicornia europeae, SP= Spartina patens, SR= Scirpus robustus.**

**Table 4. Mean percent cover of plant species per site. Means are based on nine stratified random 1m$^2$ sample quadrats.**

| **Mean Percent Cover of Plant Species per Site** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Site #** | | | | | | | | |
| **Species** | 1 | 6 | 9 | 18 | 20 | 21 | 24 | 29 | 32 |
| *Agropyron pungens* | | | | | | | | | 8.7 |
| *Ascophyllum nodosum* | 7.3 | | | 3.8 | | 8.2 | | | 3.6 |
| *Atriplex patula* | | 0.2 | | | | | | | |
| *Enteromorpha sp.* | 0.7 | | 2.2 | | | 0.9 | | | |
| *Fucus vesiculosus* | 10.2 | 1.3 | 0.7 | 0.2 | | 3.1 | | 0.2 | 0.2 |
| *Glaux maritima* | | 1.3 | | | | | | | |
| *Impatiens capensis* | | | | 3.6 | | | | | |
| *Juncus gerardii* | | 6 | 29.1 | | 18 | 8.7 | 9.8 | | |
| *Limonium nashii* | | 2 | | 0.2 | 7.6 | 1.6 | | | |
| *Phragmites australis* | | | | 45.1 | | | | 17.6 | |
| *Plantago maritima* | | | | | 0.7 | | | | |
| *Potentilla answerina* | | | 4 | | | | | | |
| *Puccinellia maritima* | | 3.1 | | | | | | | 10.2 |
| *Salicornia europeae* | | 1.8 | | | 11.6 | 1.3 | | 2.9 | 1.8 |
| *Scirpus maritimus* | | | | 0.4 | | | | | |
| *Scirpus pungens* | | 6.2 | | | | | | | |
| *Scirpus robustus* | | | 0.4 | | 7.8 | | 8.9 | | |
| *Solanum dulcamara* | | | | 0.4 | | | | | |
| *Solidago sempervirens* | | | 2.9 | | | | | | |
| *Sueda maritima* | | 0.2 | | | | | | | 1.3 |
| *Spartina alterniflora* | 79.6 | 57 | 62 | 19.8 | 43.8 | 80 | 32 | 49.1 | 54 |
| *Spartina patens* | | 4.4 | 4.9 | 11.1 | 32.2 | 18.9 | 49.1 | 23.3 | |
| *Spartina pectinata* | | | 0.9 | | | | | | |
| *Typha latifolia* | | | | 3.8 | | | | | |
| Higher plants | 79.6 | 82 | 104 | 84.4 | 122 | 110 | 99.8 | 92.9 | 76 |
| Algae | 18.2 | 1.3 | 2.9 | 4 | 0 | 12.2 | 0 | 0.22 | 3.8 |

**Table 5. Plant diversity values for nine fringing marsh sites. H', S, E values are from nine quadrats per marsh site. Total number species observed value includes species observed outside of sample quadrats. See Appendix for complete listing of species.**

| Site | H' | S | E | Total no. species observed on marsh |
|---|---|---|---|---|
| 1 | 0.187 | 4 | 0.311 | 12 |
| 6 | 0.584 | 11 | 0.526 | 17 |
| 9 | 0.524 | 9 | 0.549 | 11 |
| 18 | 0.617 | 10 | 0.617 | 20 |
| 20 | 0.696 | 7 | 0.824 | 16 |
| 21 | 0.508 | 8 | 0.562 | 13 |
| 24 | 0.502 | 4 | 0.834 | 10 |
| 29 | 0.487 | 5 | 0.696 | 10 |
| 32 | 0.468 | 7 | 0.553 | 10 |

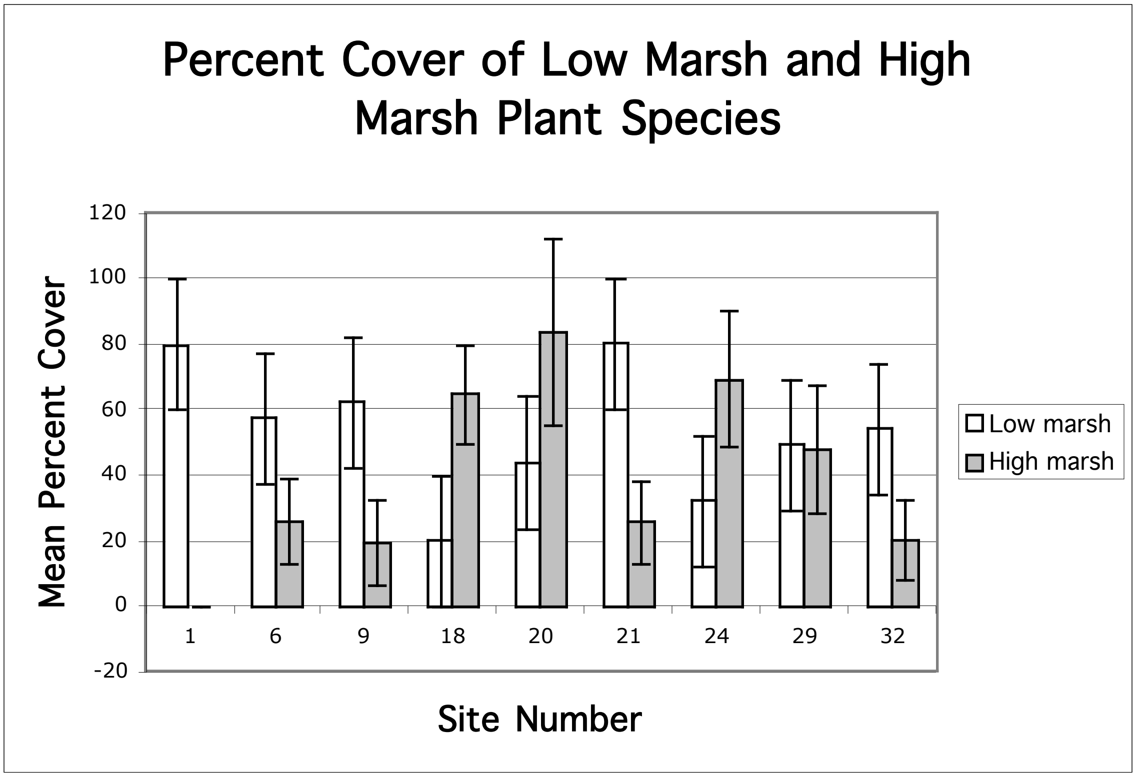


**Figure 21.** Percent cover of low marsh and high marsh plant species at fringing marsh sites. Error bars are ± 1 standard error from the mean.

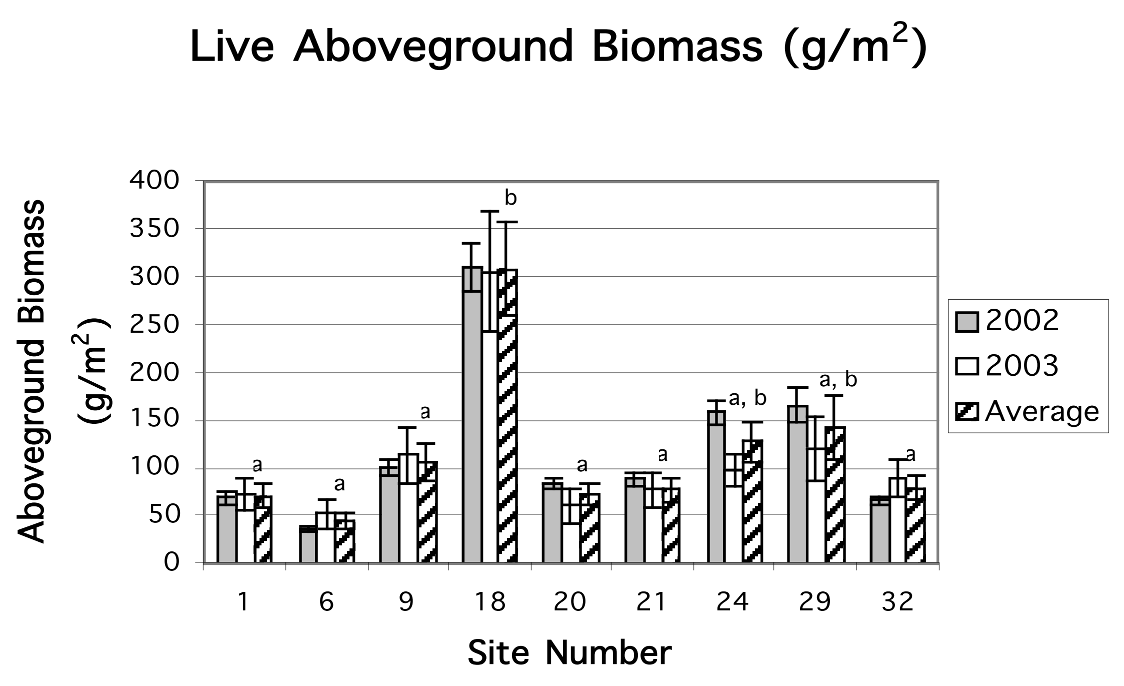


**Figure 22. Live aboveground biomass at fringing marsh sites. Error bars are ± 1 standard error from the mean. Bars representing overall averages followed by the same letter are not significantly different from one another (ANCOVA, square root transformed data, p = 0.0001, year p = 0.5730, Scheffe's p = 0.01).**

transformed data, p = 0.0001, year p = 0.5730, Scheffe's p = 0.01). Site 18 had the greatest standing crop, most likely because much of this site is dominated by *Phragmites australis* (Table 4), which covers 45% of the site. Annual values at the nine sites ranged from 35-309 g/m$^2$.

### *Dead aboveground biomass*

The amount of dead aboveground biomass at each site was also measured at the end of the growing season. Most sites had low amounts of dead material, with annual means ranging from 2-30 g/m$^2$ (Figure 23). Site 18 had significantly more dead biomass than most of the other sites, with a two year average of 118 g/m$^2$ , again due to the presence of a large population of *Phragmites australis*, which persists as standing dead material for some time (ANCOVA, square root transformed data, p = 0.0001, year p = 0.2099, Scheffe's p = 0.01).

### *Ratio of Live aboveground biomass: Dead aboveground biomass*

The ratio of live:dead biomass is illustrated in Figure 24. Most sites had more than five times the amount of live material compared to dead. The mean ratio of live:dead biomass across nine sites and both years was 9.3.

### *Stem density of Spartina alterniflora*

The mean number of *S. alterniflora* stems per square meter at the nine fringing marsh sites in 2002 and 2003 is illustrated in Figure 25. Note that quadrats including high marsh species along with *S. alterniflora* were not included in the analysis. Values ranged from a low of 90 stems/m$^2$ at site 6 to a high of 321 stems/m$^2$ at site 18. Site means were compared using ANCOVA, with year as a covariate. No significant difference in stem density was seen between sites (ANCOVA, p = 0.1895, year p = 0.6873).

## Invertebrates

Large numbers of invertebrates were found in the upper 4 cm of soil at all fringing marsh sites (Figure 26, Table 6). Densities in low marsh areas ranged from 3,643/m$^2$ at site 24 to 11,673/m$^2$ at site 9. At all but one site (site 24), the density of invertebrates was greater in the low marsh than in the high marsh. High marsh densities ranged from 1,840/m$^2$ at site 6 to 16,174/m$^2$ at site 24. At site 18, where sampling was also conducted in *Phragmites australis* – dominated areas of the marsh, far fewer invertebrates per unit area were found in the *Phragmites* compared to both low and the high marsh areas. The density of invertebrates sampled in a cattail-dominated area of site 29 was also quite low compared to other areas of the marsh.

Table 6 summarizes the types and densities of invertebrates found at each fringing marsh site. Most common were species of Clitellata, Malacostraca and Nematoda. A complete listing of the taxa identified and the densities of individuals in those taxa can be found in the Appendix.

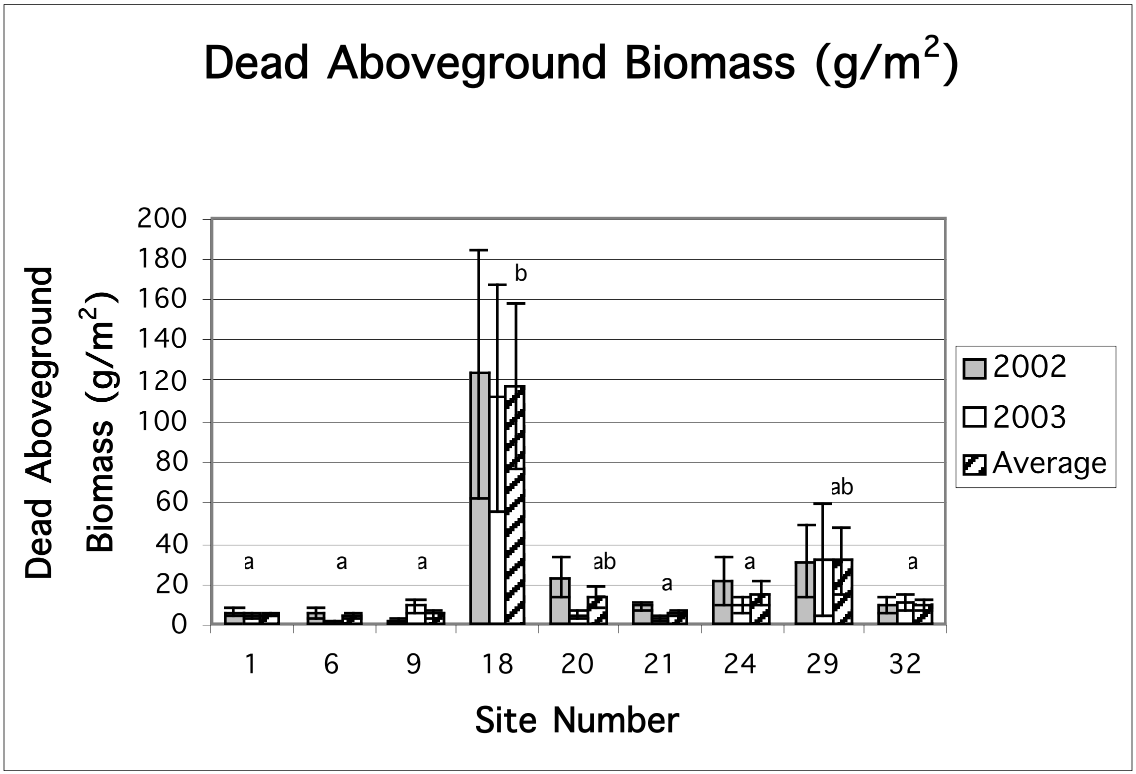


**Figure 23. Mean dead aboveground biomass at fringing marsh sites. Error bars are ± 1 standard error from the mean. Bars representing overall averages followed by the same letter are not significantly different from one another (ANCOVA, square root transformed data, p = 0.0001, year p = 0.5953, Scheffe's p = 0.01).**

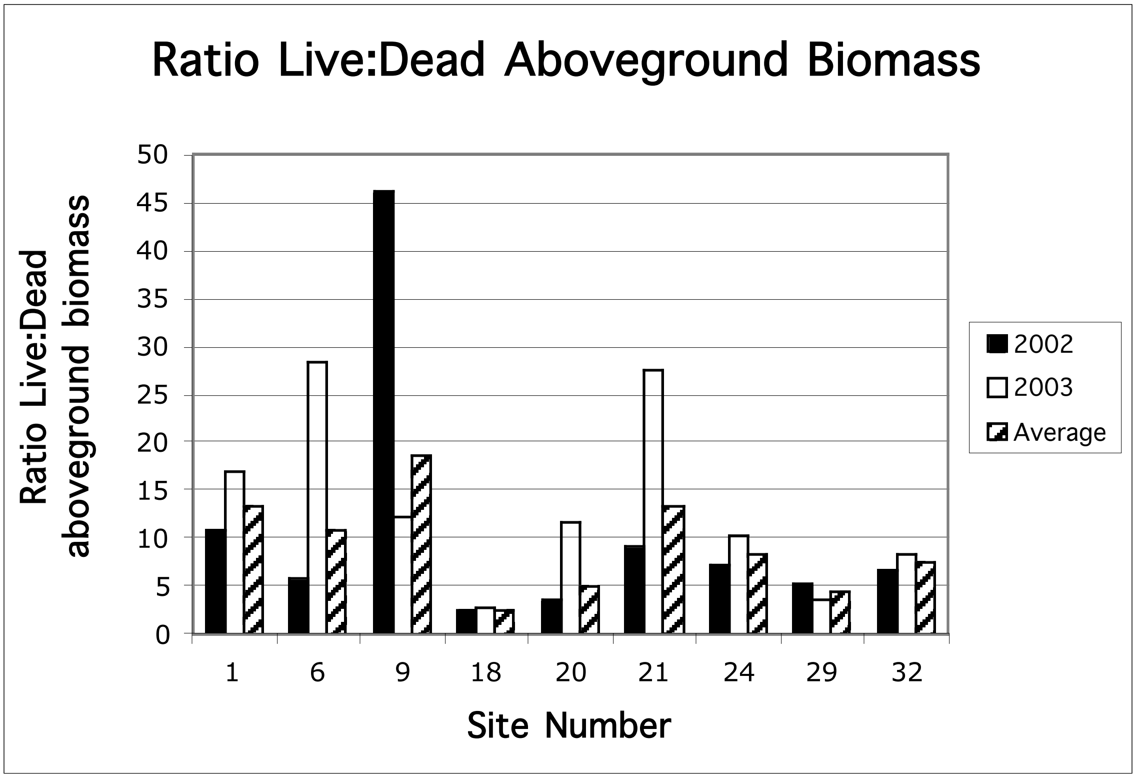


**Figure 24. Ratio of live to dead aboveground biomass for nine fringing marsh sites in Casco Bay, ME.**

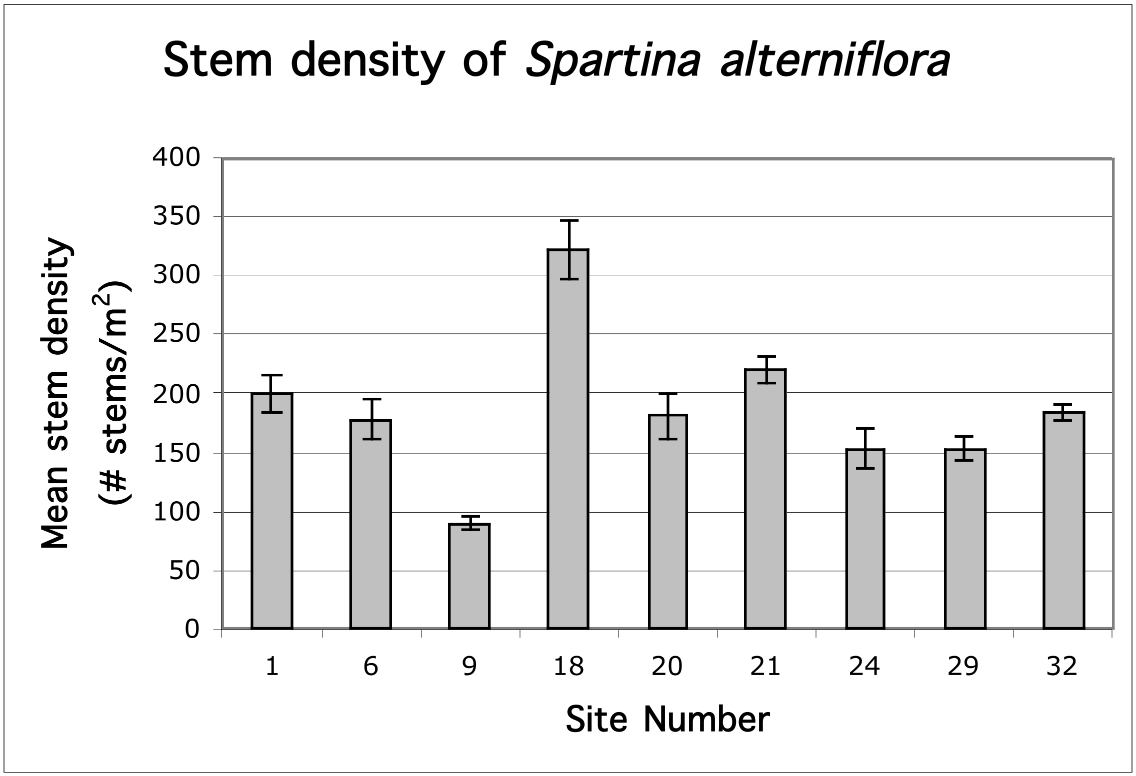


**Figure 25. Stem density of *Spartina alterniflora* at fringing marsh sites. Error bars are ± 1 standard error from the mean. Means were not significantly different from each other (ANCOVA, p = 0.1894, year p = 0.6873).**

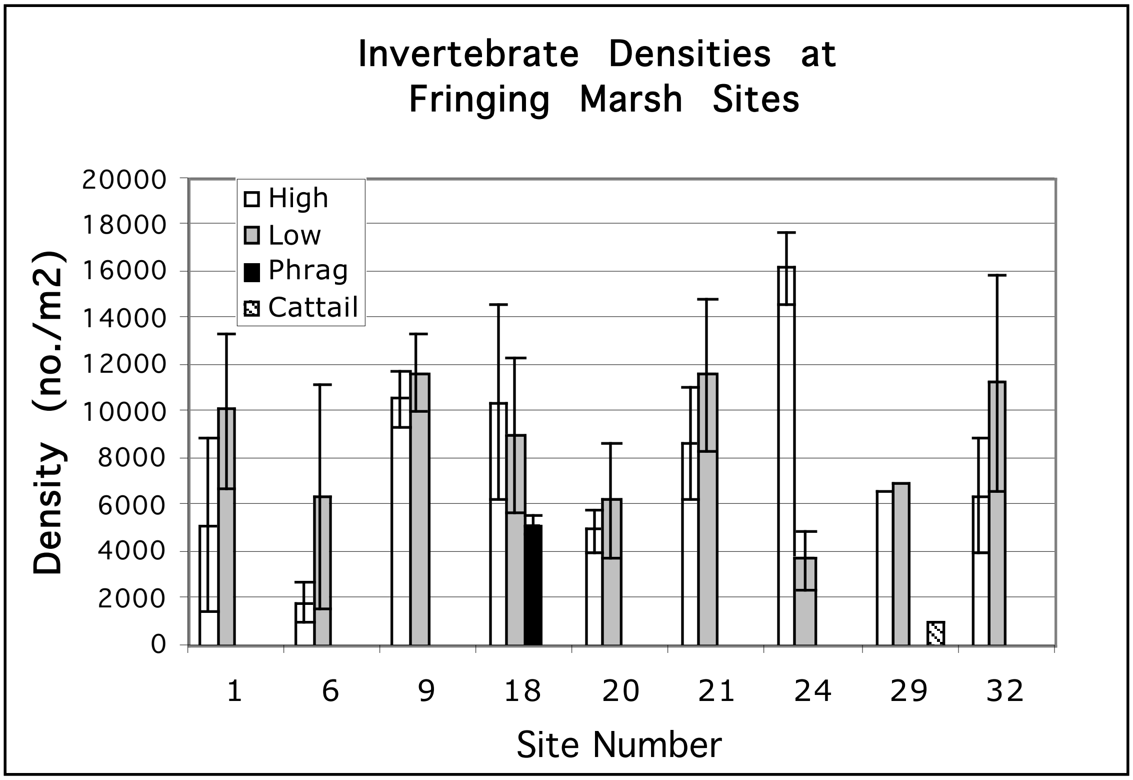


**Figure 26. Average densities of invertebrates in the upper 4 cm of fringing marsh soils. Samples were taken from 7.8 cm diameter cores in low marsh, high marsh, *Phragmities* and/or cattail areas of fringing marsh sites.**

**Table 6. Types and densities of invertebrates (no. per m$^2$) found in top 4 cm of soil at nine fringing marsh sites. Invertebrates are grouped into major taxa. Complete data set is included in Appendix.**

| | Site 1 | | Site 6 | | Site 9 | | Site 18 | | | Site 20 | | Site 21 | | Site 24 | | Site 29 | | | Site 32 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | High | Low | High | Low | High | Low | High | Low | Phrag | High | Low | High | Low | High | Low | High | Low | Cattail | High | Low |
| Annelida | | | | | | | | | | | | | | | | | | | | |
| Clitellata | 2141 | 3757 | 1655 | 3993 | 8497 | 11186 | 9023 | 2908 | 4305 | 3611 | 2938 | 5556 | 4046 | 12697 | 725 | 4471 | 5991 | 217 | 4448 | 5619 |
| Polychaeta | 403 | 113 | 0 | 218 | 21 | 73 | 51 | 1107 | 10 | 156 | 610 | 631 | 352 | 207 | 694 | 0 | 528 | 0 | 578 | 506 |
| Arthropoda | | | | | | | | | | | | | | | | | | | | |
| Arachnida | 51 | 0 | 0 | 0 | 301 | 0 | 10 | 51 | 61 | 0 | 0 | 51 | 0 | 558 | 0 | 1800 | 0 | 310 | 41 | 0 |
| Cirrepedia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 0 |
| Copepoda | 21 | 0 | 0 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 |
| Insecta | 464 | 31 | 114 | 82 | 960 | 331 | 1074 | 103 | 754 | 795 | 21 | 2295 | 103 | 1870 | 300 | 31 | 0 | 310 | 496 | 1065 |
| Malacostraca | 373 | 114 | 31 | 31 | 10 | 62 | 103 | 4150 | 31 | 0 | 755 | 20 | 4057 | 776 | 1847 | 0 | 155 | 62 | 154 | 2245 |
| Cnidaria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 31 | 31 |
| Mollusca | | | | | | | | | | | | | | | | | | | | |
| Bivalvia | 21 | 2090 | 0 | 10 | 0 | 0 | 0 | 72 | 0 | 0 | 113 | 0 | 330 | 0 | 0 | 0 | 0 | 0 | 0 | 424 |
| Gastropoda | 0 | 10 | 0 | 0 | 10 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 31 | 0 | 0 | 0 |
| Nematoda | 1645 | 3943 | 41 | 2039 | 538 | 21 | 10 | 621 | 10 | 373 | 1780 | 124 | 2628 | 41 | 52 | 279 | 248 | 0 | 507 | 1376 |
| Nemertea | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 41 | 0 | 0 | 0 | 0 | 0 |
| Platyhelminthes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 0 | 0 |
| Protista | 0 | 0 | 0 | 0 | 217 | 0 | 114 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 114 | 0 |
| TOTALS | 5122 | 10058 | 1840 | 6374 | 10586 | 11673 | 10389 | 9024 | 5174 | 4936 | 9230 | 8682 | 11559 | 16174 | 3658 | 6581 | 6954 | 900 | 6426 | 11269 |

## Nekton (fish and macrocrustaceans)

Thirteen finfish species and five decapod macrocrustacean species were collected from our fringing marsh study sites (Tables 7 and 8). Resident fishes (*Fundulus heteroclitus, Menidia menidia, Gasterosteus aculeatus, Apeltes quadracus, Pungitius pungitius, and Pleuronectes putnami*) exhibited the least variable distribution (Figure 27), and were present at all nine sites in both 2002 and 2003 (coefficient of variation (cv) equals 30% for pooled 2002-2003 data). Sites 9, 21 and 24 exhibited the highest two-year means, with site 9 experiencing high biomass density as a result of a school of 447 Atlantic silversides (*Menidia menidia*) in September 1992. Resident biomass densities exceeded those of the marine transient species (*Clupea harengus, Pseudopleuronectes americanus, Urophycis tenuis*) by four fold. Transient biomass density (Figure 28) was much more variable (67% cv), with no transient species present at five sites in 2002 (sites 1, 18, 21, 24, 32), and two sites in 2003 (sites 9, 24). Transient biomass density was highest at sites 6 and 20. Only site 20 approached biomass density similar to the higher biomass densities for resident fish observed at sites 9, 21 and 24), due to the occurrence of a school of 821 Atlantic herring (*Clupea harengus*) in June 1992. Migratory species (*Anguilla rostrata, Alosa sapidissima, Osmerus mordax, Microgadus tomcod*; Figure 29) were intermediate in variability (34% cv), present at all but two sites in 2002 (sites 1 and 18) and all but one site in 2003 (site 20). Site 9 contained the highest biomass density over two years, more than twice as high as the other sites, due to the presence of eels (*Anguilla rostrata*). Site 21 had a high biomass density in 2003, from several eels, tomcod (*Microgadus tomcod*), and 36 alewives (*Alosa sapidissima*). Mean biomass densities (in gm $m^{-2}$ for the pooled 2002/2003 data) were: 0.21 (0.061 standard error(se)) for residents; 0.05 (0.035 se) for transients, and 0.13 (0.045 se) for migratory species.

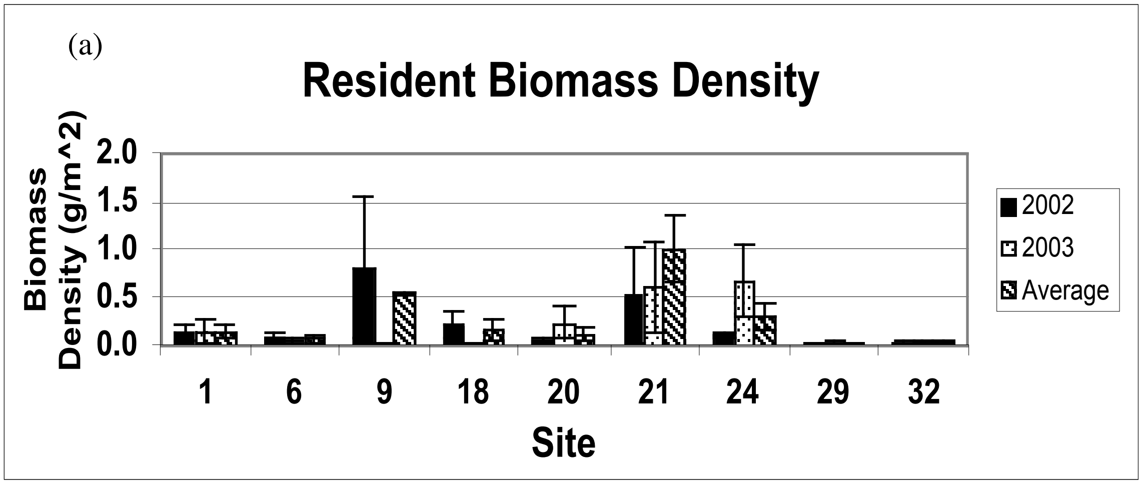
Of the five species of nektonic macrocrustaceans present at our Casco Bay fringing marsh study sites, only the green crab (*Carcinus maenas*) was present at all sites on all dates (Figure 30). Other crabs (*Cancer borealis*, *Cancer irroratus, Pagurus sp.*) occurred at four sites in 2002 only and at very low biomass densities (Figure 31). Sand shrimp (*Crangon septemspinosa*) were present at only half of the sites, and at very low biomass densities (Figure 32). Green crab biomass densities were ten fold higher (2.24 gm $m^{-2}$ (0.739 se), 33% cv for the pooled 2002/2003 data) than that of the next largest biomass group, the resident fishes (Figures 33 and 34).

**Table 7. Nekton species sampled at none Casco Bay fringing marsh sites. Species were present at one or more of the sample dates in the year(s) indicated by the "x." Sampling was conducted in June, July, August and September in 2002 and in June and August 2003. For complete listing of fish caught at sample dates see Appendix.**

| | **Site 1** | | **Site 6** | | **Site 9** | | **Site 18** | | **Site 20** | | **Site 21** | | **Site 24** | | **Site 29** | | **Site 32** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FISH** | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 | 02 | 03 |
| Alewife<br>*(Alosa pseudoharengus)* | X | X | X | | X | | | | X | | | | X | | X | | X | |
| American eel<br>*(Anguilla rostrata)* | | | X | | X | X | | X | X | | | X | X | X | X | | X | |
| Atlantic herring<br>*(Clupea harengus)* | X | X | X | X | X | | X | X | X | | | X | | | X | | X | |
| Mummichog<br>*(Fundulus heteroclitus)* | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | x |
| Tom cod<br>*(Microgadus tomcod)* | | | X | X | X | X | X | X | X | X | | | X | | | | | X |
| Three-spine stickleback<br>*(Gasterosteus aculeatus)* | | X | | X | | | | | | | | | | | X | | | |
| Four-spine stickleback<br>*(Apeltes quadracus)* | | | | X | | | | | | | X | X | X | | | | | |
| Silverside<br>*(Menidia menidia)* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X |
| Rainbow smelt<br>*(Osmerus mordax)* | | | X | X | | | | | | | | | | | | | X | X |
| Smooth flounder<br>*(Pleuronectes putnami)* | | | | | | | | | | | | X | | X | | | | X |
| Winter flounder<br>*(Pseudopleuronectes americanus)* | X | | X | X | X | X | | | X | X | | X | | | | | X | |
| Hake (Red/White)<br>*(Urophycis tenuis/Urophycis chuss)* | | | X | | X | | | | | | | X | | | | X | | |
| Nine-spine stickleback<br>*(Pungitius pungitius)* | | | | | | | | | | | | | | | | | | |
| **CRUSTACEANS** | | | | | | | | | | | | | | | | | | |
| Green crab<br>*(Carcinus maenas)* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Shrimp<br>*(Crangon septemspinosa*)* | | X | X | X | X | X | X | | X | X | X | X | X | X | X | | X | X |

## Table 8. Nekton species sampled by fyke nets at nine Casco Bay fringing marsh sites (*species sampled from nearby sites in a related study).

| FINFISH | LIFE HISTORY | FEEDING GUILD |
|---|---|---|
| **Anguillidae — Freshwater Eels** | | |
| American Eel – *Anguilla rostrata* | Resident-Catadromous | Piscivore |
| **Clupeidae — Herrings** | | |
| Alewife – *Alosa pseudoharengus* | Andromous | Planktivore |
| Atlantic Herring – *Clupea harengus* | Marine Transient | Planktivore |
| **Osmeridae — Smelts** | | |
| Rainbow Smelt – *Osmerus mordax* | Anadromous | |
| **Gadidae — Codfishes** | | |
| Atlantic Tomcod – *Microgadus tomcod* | Resident-Anadromous | Piscivore |
| White Hake – *Urophycis tenuis* | Marine Transient (j) | Piscivore |
| Pollock* – *Pollachius virens* | Marine Transient (j) | Piscivore |
| **Cyprinodontidae — Killifishes** | | |
| Common Mummichog – *Fundulus heteroclitus* | Estuarine Resident | Omnivore |
| **Atherinidae — Silversides** | | |
| Atlantic Silverside – *Menidia menidia* | Estuarine Resident | Planktivore |
| **Gasterosteidae — Sticklebacks** | | |
| Fourspine Stickleback – *Apeltes quadracus* | Estuarine Resident | Omnivore |
| Threespine Stickleback – *Gasterosteus aculeatus* | Estuarine Resident | Omnivore |
| Ninespine Stickleback – *Pungitius pungitius* | Estuarine Resident | Omnivore |
| **Percichthyidae — Perches** | | |
| Striped Bass* – *Morone saxatilis* | Marine Transient (j,a) | Piscivore |
| **Mugilidae — Mullets** | | |
| Striped Mullet* – *Mugil cephalus* | Marine Transient (j) | Omnivore |
| **Pleuronectidae — Righteye Flounders** | | |
| Winter Flounder – *Pseudopleuronectes americanus* | Marine Transient (j,a) (estuarine spawner) | Benthivore |
| Smooth Flounder – *Pleuronectes putnami* | Estuarine Resident (j,a) | Benthivore |
| CRUSTACEANS | | |
| **Crangonidae** | | |
| Sand Shrimp – *Crangon septemspinosa* | Estuarine Resident | |
| **Paguridae** | | |
| Hermit Crab – *Pagurus sp.* | Littoral | |
| **Cancridae** | | |
| Rock Crab – *Cancer irroratus* | Littoral | |
| Jonah Crab – *Cancer borealis* | Littoral - Subtidal | |
| **Portunidae** | | |
| Green Crab – *Carcinus maenas* | Estuarine Resident | |



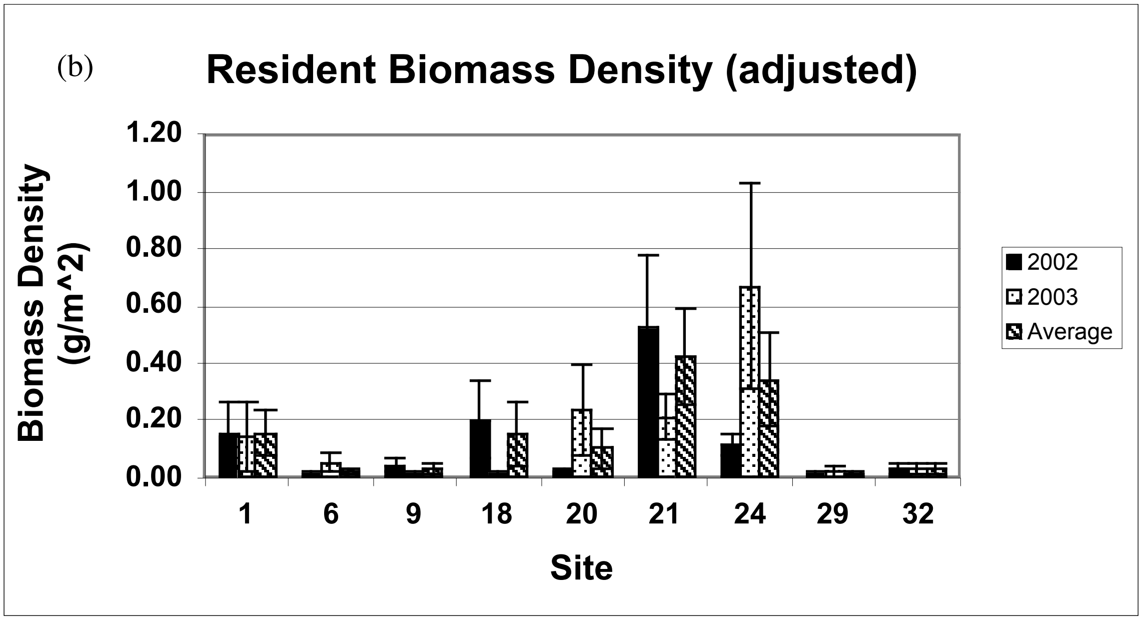
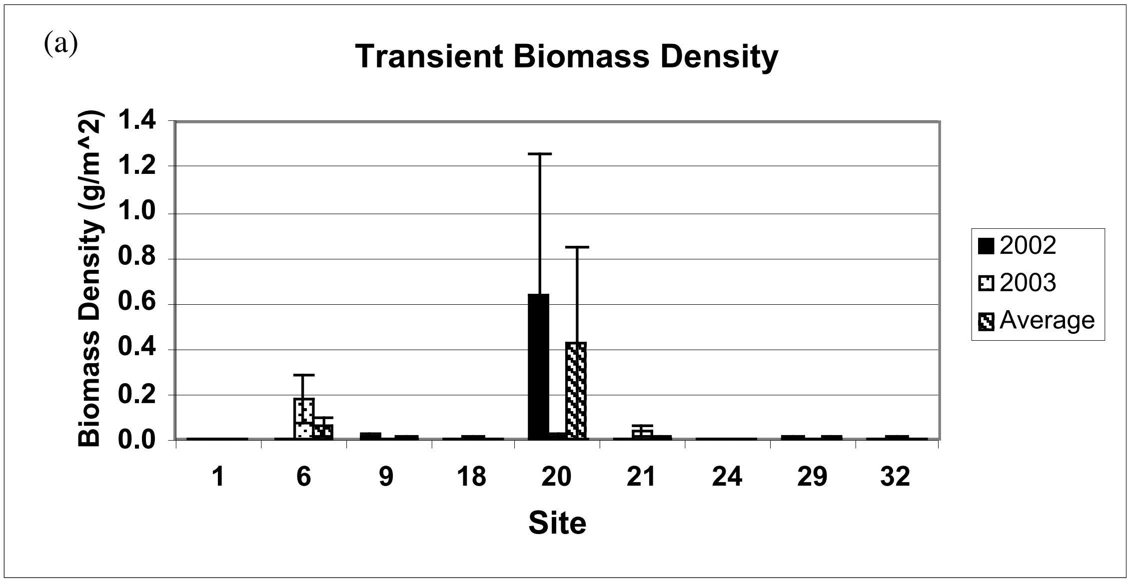


**Figure 27. a) Means and standard errors of resident fish biomass per square meter for all sampling dates by year for each site, as well as the mean of both years. Unless otherwise noted, sample size is 8 (4 dates x 2 tides) in 2002 and 4 in 2003. b) Data are adjusted by removing the influence of fish schools at Site 9 in 2002 and Site 21 in 2003.**



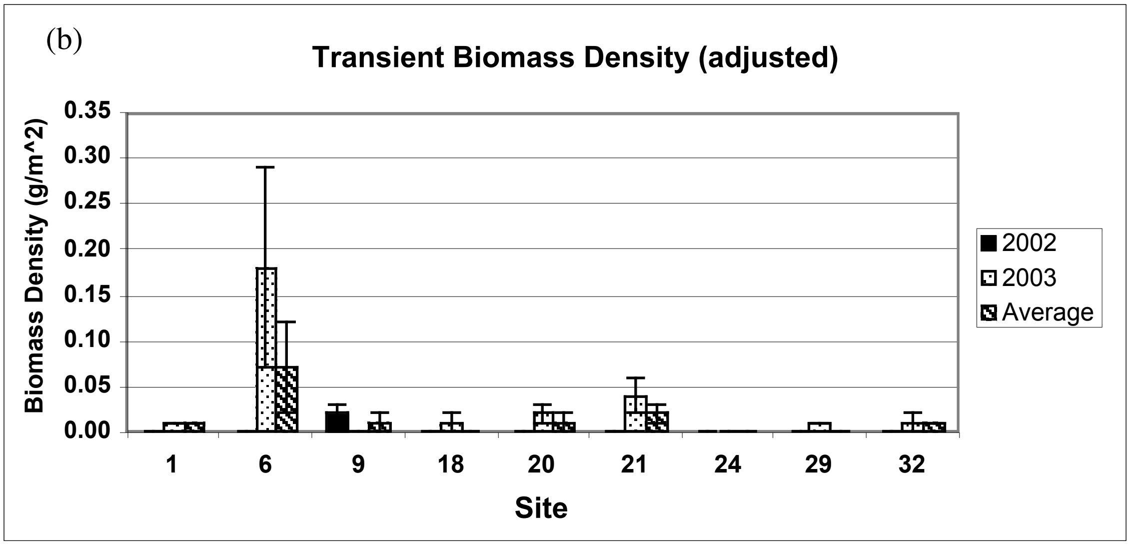


**Figure 28. a) Means and standard errors of transient fish biomass per square meter for all sampling dates by year for each site, as well as the mean of both years. b) Data are adjusted by removing the influence of fish schools at Site 20 in 2002. Note expansion of scale on y axis.**

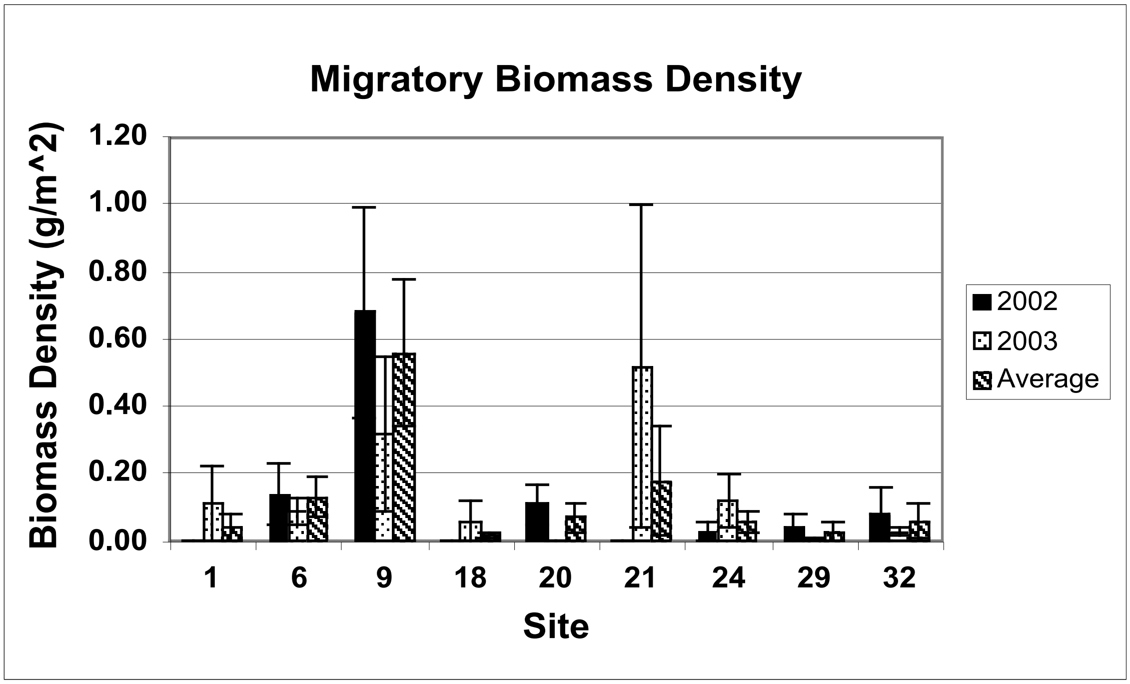


Figure 29. Means and standard errors of migratory fish biomass per square meter for all sampling dates by year for each site, as well as the mean of both years.

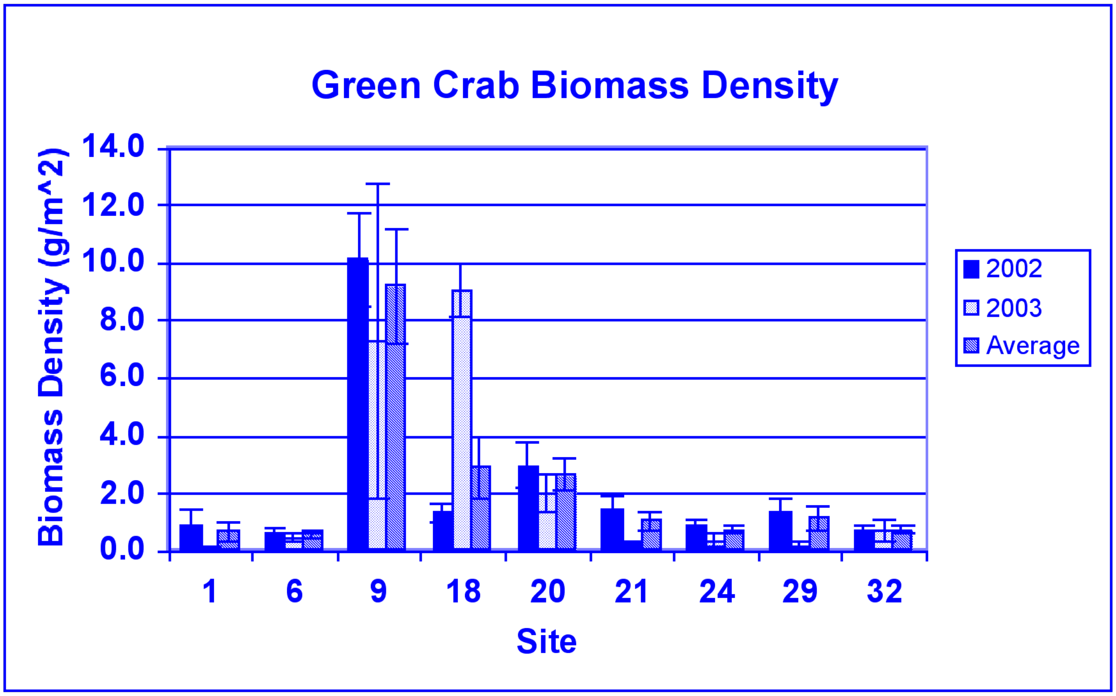


Figure 30. Means and standard errors of green crab biomass per square meter for all sampling dates by year for each site, as well as the mean of both years.

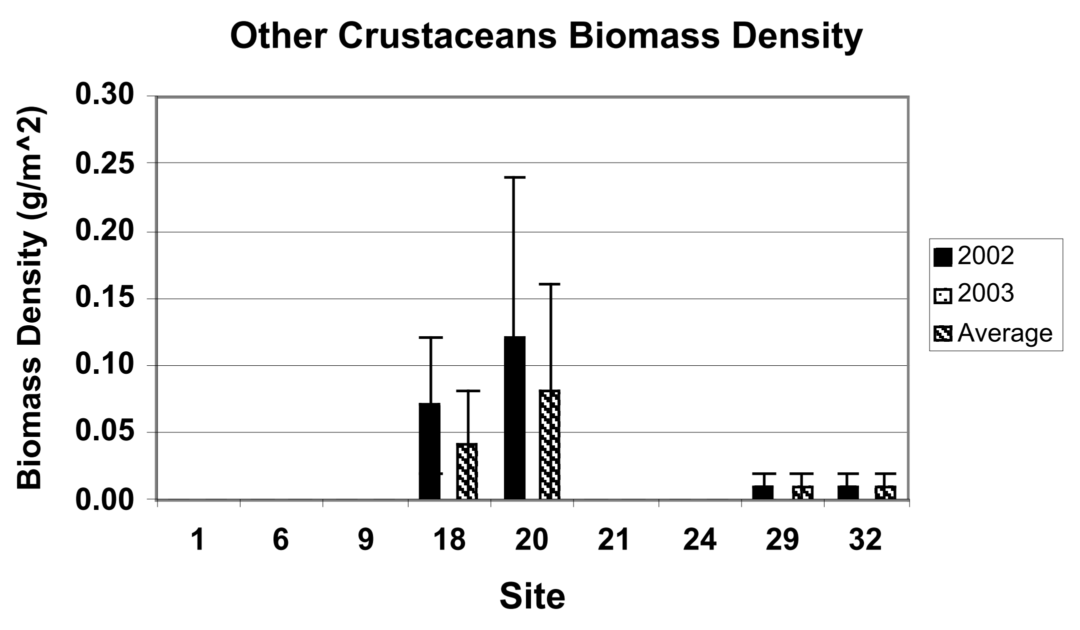


Figure 31. Means and standard errors of other crustacean biomass (jonah crab, rock crab, hermit crab) per square meter for all sampling dates by year for each site, as well as the mean of both years.

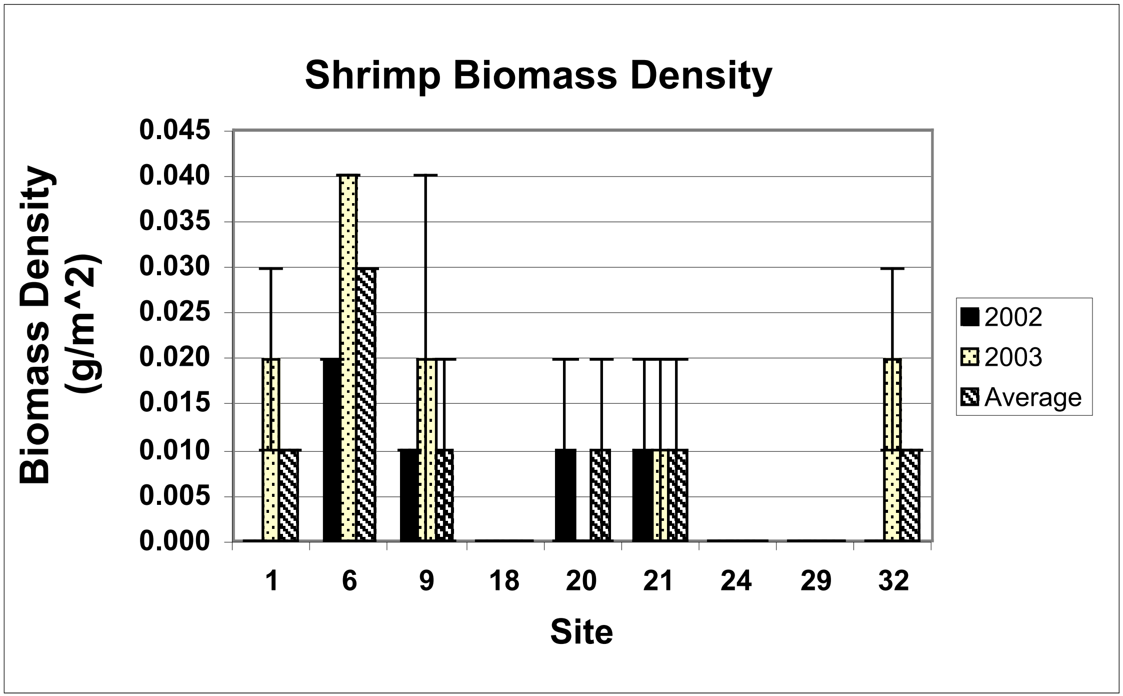


Figure 32. Means and standard errors of shrimp biomass per square meter for all sampling dates by year for each site, as well as the mean of both years. Note the greatly expanded scale on the y axis.

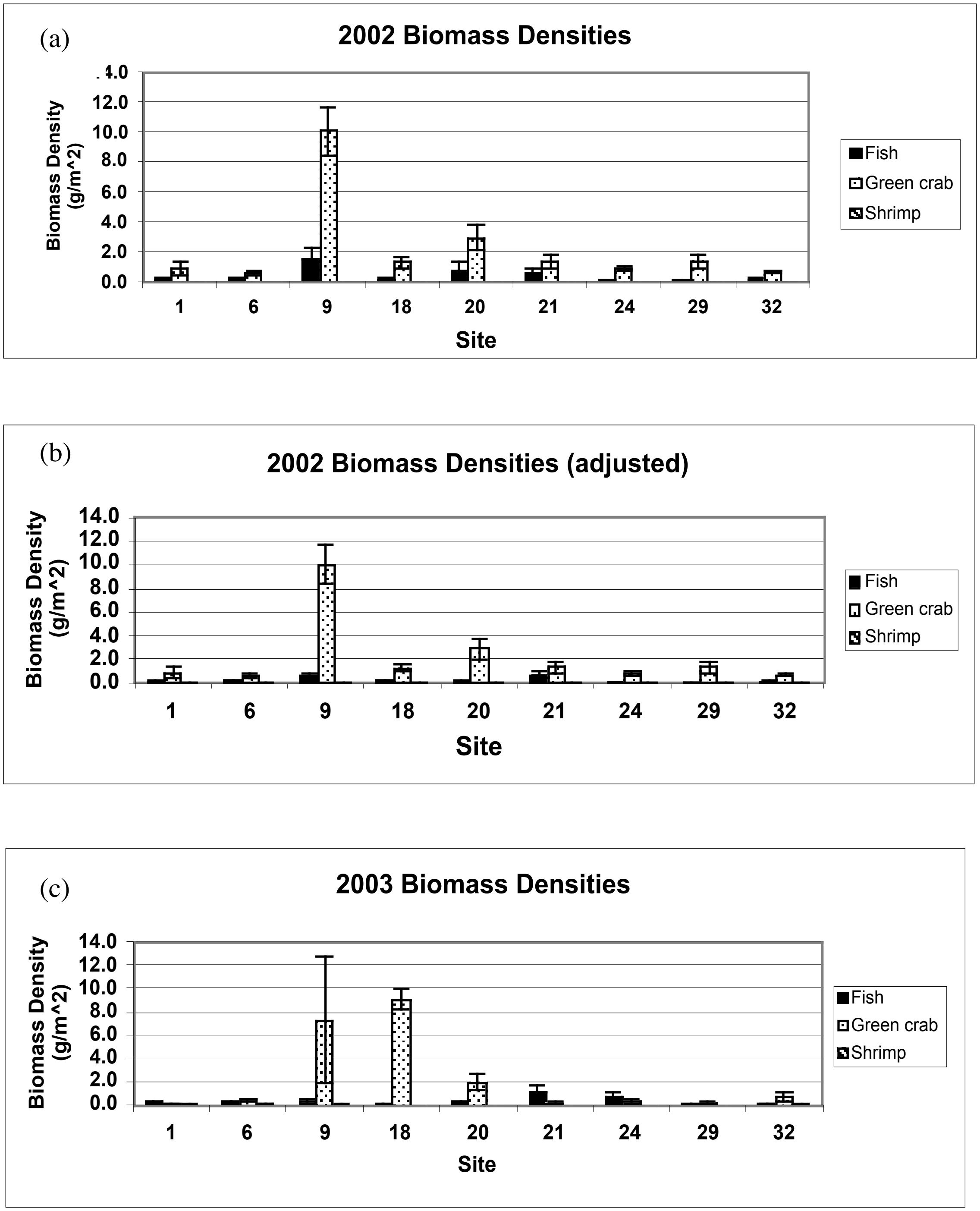


**Figure 33. a) Means and standard errors of biomass per square meter for fish (all species combined), green crab, and sand shrimp for all sampling dates in 2002 for each site. b) Data adjusted by removing the influence of fish schools at Site 9 and Site 20. c) Fish, green crab and sand shrimp in 2003.**

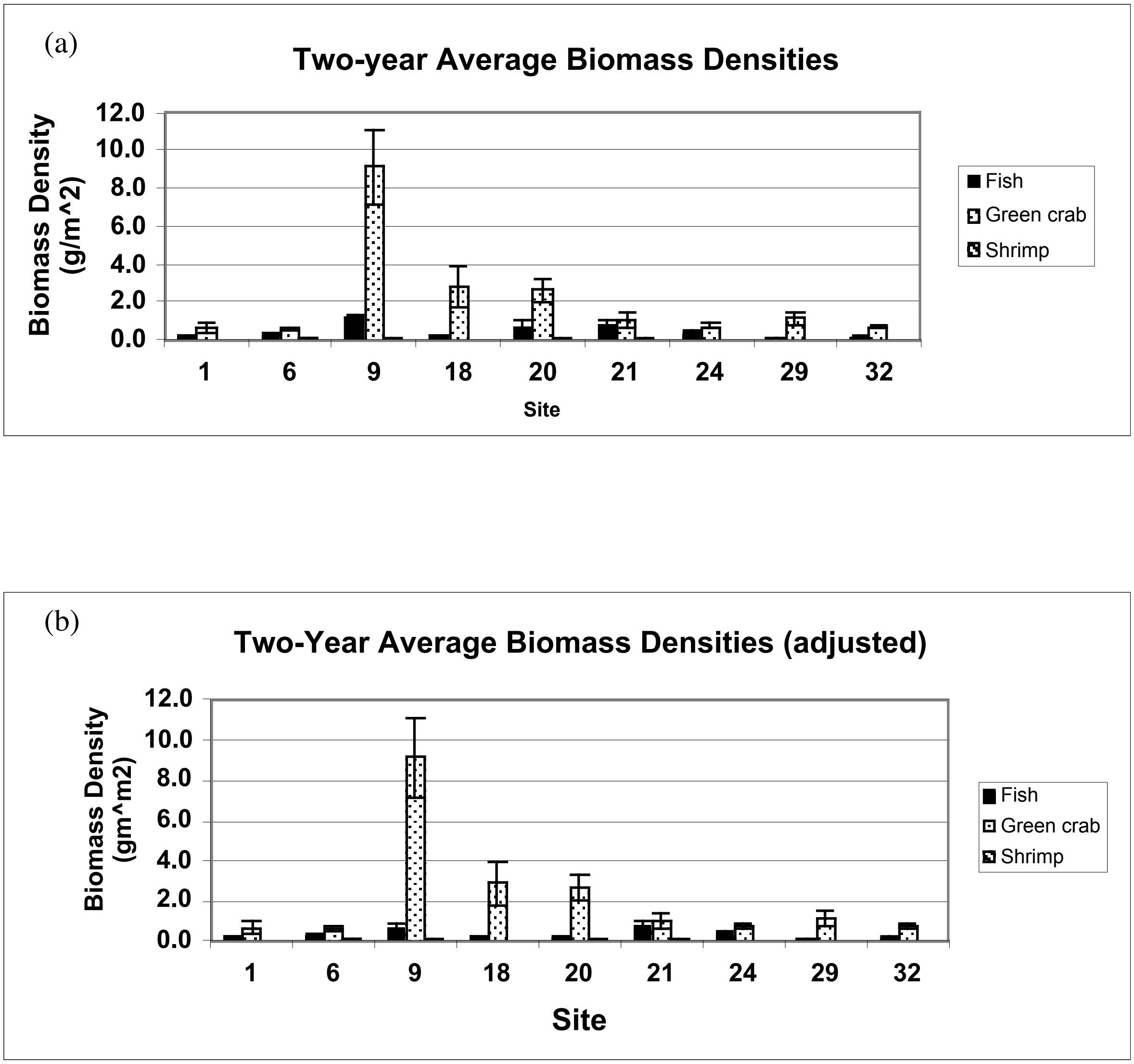


**Figure 34. a) Means and standard errors of biomass per square meter for fish (all species combined), green crab, and sand shrimp based on annual means for 2002 and 2003 (shown in Fig. 33). b) Data adjusted by removing the influence of fish schools at Site 9 and Site 20.**

# DISCUSSION

## Study Site Mapping

Our mapping of the nine fringing salt marsh sites included in this study is the first effort to determine the exact location, boundaries and size of these coastal marshes in Casco Bay. Because of their small size, fringing marshes are difficult to see on aerial photos such as those available from the Maine Office of GIS, which are at a scale of 1:24,000 (Figures 6-14). The use of highly accurate GPS receivers in the field enabled us to delineate the fringing marshes on these aerial photographs. In the event of spill in Casco Bay, it will be important to be able to locate salt marshes potentially affected by the spill in a timely manner. We recommend that a more comprehensive mapping effort be undertaken in the future to determine the locations and boundaries of the fringing salt marshes in Casco Bay.

A previous effort to determine the extent of salt marshes along the entire Maine coast (Jacobson et al. 1987) used photointerpretation of 1:24,000 scale photographs taken in 1960 to measure individual marsh areas. The results of this study were enlightening, as they showed that the number of small salt marshes far exceeds that of the large marshes along the Maine coast. Marshes smaller than the mean size for the state (0.026 $km^2$ or 26,000 $m^2$) comprised more than 40% of the total salt marsh acres measured. With current GPS/GIS technology and the methods we have developed, these small salt marshes should be mapped where there is a greater likelihood of environmental impacts.

Our mapping effort also allowed us to determine the locations and amounts of the low and high marsh plant communities at the sites we studied (Table 2). This baseline information will be helpful in determining the impact of future spill events (or other anthropogenic impacts) on the extent of low and high marsh salt plant communities at these sites.

## Physical characteristics of fringing marsh sites

The results of our survey of the physical characteristics of the nine fringing marsh sites (including site width, surface slope, fetch, elevations and salinity) demonstrated the wide variation that occurs in these characteristics (Figures 15 & 16). Because structural and functional characteristics of salt marshes can correlate with physical characteristics (Morgan and Short 2000), identifying the range of values at any one site can help us to understand why a particular fringing salt marsh functions as it does. Knowledge of a site's width, elevation and slope is also important in restoration efforts. If a marsh is impacted and restoration is necessary, we must know what we are restoring the site to. The physical, or structural components of a salt marsh must be correct for the marsh to function as a healthy salt marsh.

## Sediment trapping

The amount of sediment deposited on the surface of these nine Casco Bay sites (over a two week period) was similar to what we have observed at other fringing marsh sites in southern Maine and New Hampshire (Morgan and Short 2000). Although mean values at the Casco Bay sites ranged from 2.24 g/m$^2$/day at site 20 to 9.82 g/m$^2$/day at site 24 (Figure 17b), there were few significant differences among sites, likely due to the variation observed within a site. More sediment is usually deposited on the marsh surface closer to the water's edge than farther back on the marsh (Stumpf 1983, Reed 1992, Leonard 1997, Morgan and Short 2000).

The rate of sediment deposition on the marsh surface and the rate of erosion are important, because these rates determine whether a salt marsh is drowning, expanding, or being maintained over time (Phillips 1986). High wave energy and sea level rise are well known contributors to the loss of fringing marsh area (Finkelstein and Hardaway 1988), but impacts such as oil spills can also have significant effects. Hampson and Moul (1978) found that three years after an oil spill affected a Massachusetts salt marsh, the rate of erosion at the impacted site was 24 times the rate observed at a nearby reference site. It is therefore important to have baseline data for comparison following an impact such as an oil spill.

Wood et al. (1989) measured sediment accumulation on Maine salt marshes over a year's time using marker horizons, and observed accumulations ranging from 0 to 10 mm/yr, which is consistent with our results (Figure 19). Several of the sites they studied were in Casco Bay, where rates ranged from 0 to 5.8 mm/yr in 1986-1987, compared to our results ranging from 0 to 6.3 mm/yr in 2002-2003. For reference, sea level rise measured in Portland, Maine, averaged 2.2 mm/yr from 1930 through 1992 (Kelley et al. 1996).

More comprehensive monitoring of erosion and sedimentation rates of Casco Bay's fringing salt marshes is necessary in order to know how these fringing salt marshes are faring at maintaining their elevations and boundaries in the face of impacts such as sea level rise. In addition, being able to monitor and restore marshes impacted by oil spills will be essential to the long-term survival of these narrow strips of marsh. Our study results contribute important baseline information to that effort.

## Plant diversity

Studies of the effects of oil spills on the plant diversity of salt marshes have revealed that oiling affects plant species composition for the following reasons (Burger 1997, Scholten et al. 1987):

1. Oiled seeds will not germinate and oiled flowers will not produce seeds.
2. Annuals are more susceptible than perennials to oiling, due to shallow root systems and no belowground storage organs. Recolonization after a spill by perennial plants can lead to the exclusion of annual species.
3. Oiling of shoots affects plant growth, which in turn may reduce competition from some species, allowing others to spread.

Because of the known effects of oil spills on plant diversity, it is important to have baseline information about the species composition of salt marshes in areas susceptible to oil spills. Our results show that there is great variety in the plant species and the extent of coverage of those species from one fringing salt marsh to another (Figure 20). Even the percent of high marsh and low marsh varies substantially from site to site, with some sites being predominately high marsh communities and others almost exclusively low marsh (Figure 21). Knowledge of the plant communities of individual sites therefore becomes important in restoration efforts. Ideally, the plant communities of all of the Casco Bay fringing salt marshes should be mapped. The next best thing is to have good examples of a number of fringing salt marsh plant communities that could be used as references in the event of a spill. The data presented in this report provide this information.

It should be noted that two potentially invasive species were observed in a number of the Casco Bay sites we studied: *Phragmites australis* (common reed) and *Lythrum salicaria* (purple loosestrife) (Tables 4 & A8). Invasive species often colonize and/or spread onto a salt marsh following an anthropogenic impact, so future monitoring efforts should make special note of these species.

### Aboveground production of marsh vegetation

The impacts of an oil spill to marsh vegetation can vary widely depending on the toxicity of the oil, time of year of the spill, energy of the shoreline and the marsh site's soil composition (Burger 1997, Hershner and Moore 1977, Lin and Mendelssohn 1996). Recovery of plants has been observed to occur in a relatively short time (1-3 years) in some cases, but has taken decades in other cases (Burger 1997). Typical measurements made after an oil spill are aboveground plant productivity and stem density, so we measured these parameters at the nine study sites. The ratio of live:dead standing biomass is also sometimes calculated, so we determined this ratio as well.

There was very little variation from year one to year two of the study in the year-end standing aboveground biomass of the sites (a commonly used metric to estimate productivity) (Figure 22). All but one site had statistically similar values, which averaged 70 g/m$^2$ in 2002 and 88 g/m$^2$ in 2003. These results will provide good baseline information in the event of a future spill in Casco Bay.

### Invertebrates

Although the impacts of oil spills on salt marsh plants has been studied extensively, very little research has been conducted on the fate of the invertebrates living in and on salt marsh soils that have been oiled, despite the fact that these organisms are critical components of the salt marsh food web. Benthic invertebrates inhabiting marsh surfaces are known to be an important link between marsh production and higher trophic levels (Currin et al. 1995, Haines and Montague 1979, Kneib and Stiven 1978, Rietsma et al. 1982), and are thus an important energy source for fish and crustaceans (e.g., Kneib et al. 1980, Weisberg and Lotrich 1982, Kneib 1997).

In one study of an oiled Massachusetts salt marsh, researchers sampled the invertebrates found in the upper 4 cm of the marsh three years after the oil spill (Hampson and Moul 1978). They found that the common ribbed mussel (*Modiolus demissus*) acted as an opportunistic species, repopulating the impacted marsh to much greater numbers than what they observed at the control site. Other populations of invertebrates (nematodes, harpacticoid copepods, oligochaetes, Diptera larvae, tanaids, polychaetes) were "extremely reduced."

In addition, a recent study (Reddy et al. 2002) reported high levels of petroleum residues persisting in the soils of another Massachusetts salt marsh more than 30 years after a spill. The authors reported that visually, the marsh looked healthy, as it was covered with an abundance of marsh plants. But beneath the surface, oil remained. This study points to a need for further investigations of the belowground populations living in oiled salt marshes, as they will be most affected by the persistent oil residues. Our study provides extensive information on the types and numbers of invertebrates that are found in fringing salt marsh habitats in Casco Bay (see Appendix for complete data set). This information will not only be invaluable to those assessing the impacts of future oil spills in the Bay, but it also has the potential to be used by researchers around the Gulf of Maine in the development of biological indicators. In addition, the catalogue of the invertebrates sampled in this study, which are now stored at the Wells Estuarine Research Reserve, could be finalized and released to the public as a guide to marine invertebrate identification.

### Nekton (fish and macrocrustaceans)

The species list, biomass densities and relative abundances of functional nekton groups acquired in this study provides an initial set of benchmarks upon which to build a program to assess long-term change in Casco Bay tidal marsh habitats. The surprisingly high densities of the non-native intertidal green crab provide a compelling basis for future research to investigate the influence of this large, ecologically novel, biomass compartment on secondary production and energy flow through the coastal food web.

The large temporal and spatial variation exhibited by nekton is a function of the modest sample size, minimal temporal stratification of the sampling effort, and the mobility and relatively low densities that typify the nekton. Given the rich data set of biotic and abiotic variables collected during this study (plants, sediments, slopes, geography, invertebrates, nekton), we would like to explore the data using multivariate techniques to discover underlying associations that can account for some of the observed variation in nekton species distribution and abundance.

The nekton data collected during this study provide valuable information for use by other state and federal agencies concerned with the management of fish and wildlife (e.g. state inland fish and marine resource agencies, the USFWS and NOAA Fisheries). The tidal marsh nekton data set we are developing with support from MOSAC and USEPA is the most comprehensive data available for fish utilizing tidal marshes in the Gulf of Maine.

The diversity of nekton species sampled in the fyke nets (Tables 7 and 8) indicates that this technique provides more complete information than other methods more commonly used in salt marsh habitat, such as minnow traps, seine nets and lift nets.

The next step in the interpretation of these data is to compare the nekton biomass estimates from Casco Bay fringing marshes to those from other studies, nearly all of which have been conducted south of Maine, in systems from Buzzards Bay (Massachusetts) to Georgia.

We suggest that nekton monitoring become part of a toolkit available for routine, long-term assessment of Gulf of Maine fringing marsh habitats. Without direct measurement of nekton, it is not possible to assess the food web support functions of fringing marshes. Fully functional and self-sustaining salt marshes provide benefits to coastal human populations in terms of their amelioration of non-point source pollution and flooding, and in terms of the abundant resources they provide to support healthy coastal fish and bird populations.

## Management Implications and Recommendations

The results of this study provide resource managers with important information about the fringing salt marshes that line Casco Bay. Knowledge of these local habitats will be invaluable in improving the effectiveness of oil spill cleanup operations, accurate assessment of natural resource damages caused by spills, and the restoration of impacted sites.

It is well known that the severity and types of impacts resulting from an oil spill can vary greatly depending on the type and amount of oil spilled, time of year of the spill, weather conditions at the time of the spill, energy of the shoreline, and soil composition (Burger 1997, Lin and Mendelssohn 1996, Hershner and Moore 1977). It has also been observed that salt marsh cordgrass (*Spartina alterniflora*) can recover from a small spill (acute spill), but not from repeated oilings (chronic spill) (Burger 1997). Understanding the spill event can therefore help resource mangers to predict the effects of an oil spill and to help mitigate these effects.

In addition, there have been many studies that have focused on which cleanup methods are best to use after salt marshes have been impacted by oil. Cleanup techniques may include vacuum/pumping, low-pressure flushing, vegetation cutting, burning, bioremediation, sediment removal/replanting, or natural degradation (no response) (Hoff 1995). Past experience has shown that selecting the right cleanup technique for the situation is important, as an inappropriate response can cause more harm than good. Two recent reports offer advice concerning cleanup options (Hoff 1995, Zhu et al. 2004).

Although these reports and recommendations provide invaluable assistance to resource managers, they all state that knowledge of the local habitats is essential in order to make good spill-response decisions. The complexity of marsh ecology and the variation in salt marsh structure and function from one coastal area to another mean that good baseline information about local salt marshes is essential. The results of our study provide these baseline values for a range of fringing marsh sites in Casco Bay. These values can be used to assess the structures and functions of individual marsh sites in the Bay that may be impacted by a future spill. In addition, the report's Appendix provides means, ranges, and 95% confidence intervals for the parameters we measured at the nine fringing salt marshes included in this study. This information represents our best knowledge to date of an "average" fringing salt marsh in Casco Bay. These mean values can be used for comparative purposes in future monitoring and/or assessment efforts related to fringing salt mashes in the Bay. In addition, the results of this study can be used to select those parameters to measure that are least variable from site to site or from year to year. Future studies could evaluate the various parameters we measured and assess which would be most useful in determining the current state of a particular fringing salt marsh. The wealth of information we have gathered about plant, invertebrate and fish communities could be further analyzed to develop some key indicators of healthy fringing salt marshes.

In addition, we recommend that the methods and procedures outlined here for monitoring sediment deposition/erosion, vegetation, invertebrates, and nekton become part of a toolkit available for routine, long-term assessment of Gulf of Maine fringing marsh habitats. The results of our study and of future monitoring studies could be also be used to develop a set of indicators of the state of Casco Bay's fringing salt marshes. In addition, we also recommend follow-up studies that would continue mapping the Bay's fringing salt marshes. These maps would enable resource managers to quickly locate fringing marsh habitats in the event of a spill, and would provide baseline information about the boundaries of the sites, as well as the extent of their high marsh and low marsh communities.

The fringing salt marshes that line Casco Bay are a valuable resource to the citizens of southern Maine. In addition, they play a vital role in the ecology of the Estuary. We hope that the results of this study will enable resource managers to better to protect, conserve and restore these important habitats.

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# APPENDIX