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by

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EXECUTUVE SUMMARY

Casco Bay has experienced two significant oil spills in recent history - the Tamano Tanker spill in 1972 and the Julie N spill in 1996. In addition, the Fore River and its tributaries have experienced numerous small spills over the years, including the August 2002 fuel oil spill (2,900 gallons) and the April 2003 jet fuel spill (6,000 gallons). The impacts of these spills on the fringing salt marshes that line the edges of the Fore River and its tributaries are not well understood. Are these salt marshes resilient enough to withstand these impacts and still act as healthy marshes should? Or are they functioning at lower levels, compared to other fringing salt marshes in Casco Bay?

We studied three fringing salt marshes along the Fore River (FR) and three marshes outside the Fore River (Casco Bay reference sites (CBR)) in order to assess the primary productivity, invertebrate diversity, fish communities and plant diversity of the FR sites compared to the CBR sites. We found that although plant productivity at the FR sites was similar to that of the CBR sites, there were differences in the invertebrate, fish and plant communities between the two areas. The density of invertebrates in the low marsh zone was less in FR sites, as were the numbers of nematodes and malacostracans, especially *Corophium* sp., which is intolerant of hydrocarbon contamination. Gastropods, especially *Hydrobia* sp. (an opportunistic species and early colonizer following a disturbance), was found only at FR sites. We also observed that FR sites supported fewer fish species than CBR sites. However, the numbers and biomass of the invasive green crab were much lower at FR sites compared to CBR sites, and fish biomass density was greater at FR sites. In addition, fewer species of plants were found at FR sites compared to CBR sites. And, the FR site plant communities were significantly less diverse than the plant communities at the reference sites.

Further study of the FR and CBR sites is needed, due to the limited sampling we were able to accomplish in this study. However, the results that we obtained are similar to what has been observed in other studies of salt marshes that have been impacted by oil spills. We therefore conclude that the FR salt marshes are not functioning at the level of salt marshes outside the river, and this is most likely due to recent spill events in the river.

We recommend further monitoring of these sites, so that it can be determined if they are on a recovery trajectory, or if they will continue to function at lower levels than other Casco Bay salt marsh sites. We also recommend that the Fore River sites be protected to the greatest extent possible from future hydrocarbon spills, as well as from other impacts that could hinder their recovery. In addition, the data we have collected here, in combination with the results of our 2002-2003 study of Casco Bay fringing salt marshes, could contribute to the development of some key indicators of healthy fringing salt marshes.

The salt marshes that line the Fore River provide an important suite of functions and values to the citizens of southern Maine. The results of this study will help resource managers in their efforts to protect these important and unique natural resources.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

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INTRODUCTION

Casco Bay has experienced two significant oil spills in recent history - the Tamano Tanker spill in 1972 and the Julie N spill in 1996. In addition, the Fore River and its tributaries have experienced numerous small spills over the years, including the August 2002 fuel oil spill (2,900 gallons) and the April 2003 jet fuel spill (6,000 gallons). The impacts of these spills on the fringing salt marshes that line the edges of the Fore River and its tributaries are not well understood. Are these salt marshes resilient enough to withstand these impacts and still act as healthy marshes should? Or are they functioning at lower levels, compared to other fringing salt marshes in Casco Bay?

The cleanup after the Julie N spill was far superior to what occurred after the spill in 1972, and its effectiveness was evaluated and documented in a report prepared for the Maine DEP (Reilly 1998). Although the impacts to important coastal resources including vegetation and finfish were assessed immediately following the spill, follow-up since that time has been limited. In the original assessments, impacted sites were re-surveyed one year after the spill in an attempt to see if recovery was occurring. At this time, signs of stress were still visible in salt marsh plant communities that lined the Fore River. A finfish survey using beach seines was conducted at three sites along the Fore River and also at a reference site in Back Cove, but no conclusions were drawn from this study, most likely due to the low number of samples collected (Reilly 1998).

We returned in 2004 to some of the salt marsh sites impacted by the Julie N spill in 1996 and to subsequent smaller spill events in order to assess the current condition of these marshes. Prior to this study, in 2002 and 2003, we studied (with support from the Maine Oil Spill Advisory Council) fringing salt marshes in Casco Bay outside of the Fore River. We learned about their ecological functions and their contributions to the Estuary. Specifically, our focus was on the value of these marshes to invertebrate and finfish production, to vegetation production and diversity, and as buffers against sea level rise and coastal erosion. Although much has been learned about larger salt marshes in New England, very little research has focused on fringing salt marshes, with the exception of a study by Morgan et al. (2000). The MOSAC study helped us to understand how healthy fringing salt marshes in Casco Bay function. Our 2004 study of selected sites in the Fore River and outside of the impact area has enabled us to determine which functions of the Fore River marshes (if any) are impaired and in need of restoration.

The objectives of this study were to:

1. Study the following salt marsh functions (and their associated values) at sites within the Fore River:
    - (a) Primary production
      (*Value*: Support of food webs)
    - (b) Maintenance of animal (invertebrate) diversity
      (*Value*: Support of shellfish, finfish production)
    - (c) Provision of habitat for fish
      (*Value*: Support of shellfish, finfish production)
    - (d) Maintenance of plant diversity

(*Value*: Provide habitat for animals, Provide high biodiversity)

2. Gather physical characteristic data at each site, including elevation and soil salinity.
3. Compare functions (listed in (1) above) of Fore River sites to Casco Bay reference sites (selected from our 2002-2003 study sites which are outside of the Fore River).
4. Compare results of this 2004 survey with results of the post-Julie N spill assessment (Reilly 1998).
5. Assess the health of Fore River salt marshes and make recommendations for restoration/recovery.
6. Recommend a plan of action for the Fore River salt marshes.

METHODS

Study Site Selection

During the spring of 2004, we met with Seth Barker of the Maine Department of Marine Resources to discuss and visit potential fringing salt marsh sites in the Fore River for this investigation. Three sites were then selected in the Fore River and three sites were selected outside of the Fore River (Figure 1). For the purposes of this report, these sites will be referred to as the "Casco Bay reference sites." The Fore River sites were chosen based on their known exposure to impacts from spill events. Site F1 (Mill Creek Cove) (Figure 2a) had most recently been impacted in February 1997 by about 16,800 gallons of gasoline, when a spill occurred as Gulf Oil Terminal tanks were being filled. Site F2 (Pleasantdale Cove) (Figure 2b) had most recently been impacted in the spring of 2003, when 6,000 gallons of jet fuel had spilled from an overturned truck on Broadway, ending up on the salt marsh. Site F3 (Figure 2c), located farther upstream near Stroudwater crossing, had been impacted by the Julie N oil spill in September 1996, when oil had affected most of the Fore River shoreline to varying degrees (Reilly 1998). The three Casco Bay reference sites chosen for this study were fringing marshes that we had studied in 2002-2003, as part of a Maine Oil Spill Advisory Committee grant (Morgan et al. 2005) (Figures 2d-f). Table 1 lists the sites and their specific locations.

Physical characteristics of fringing 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.

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

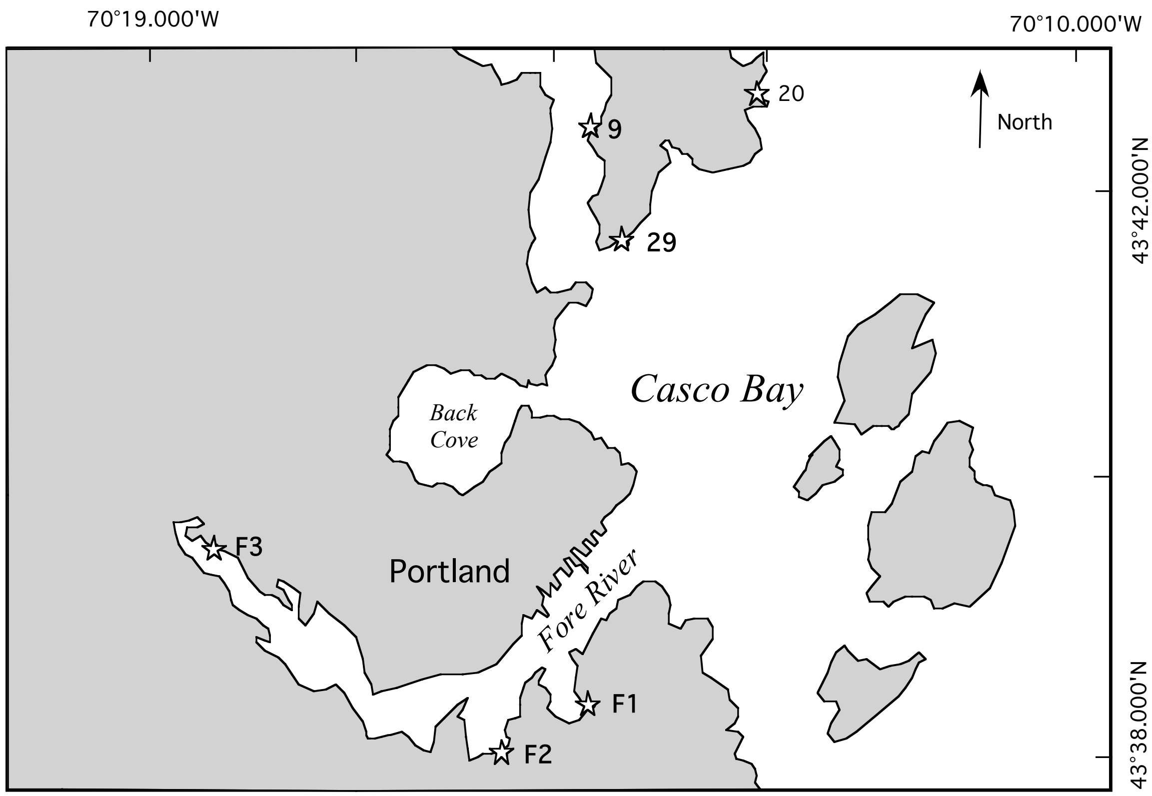


Figure 1. Location of fringing marsh study sites. Sites designated with an "F" are located in the Fore River; sites designated with numbers alone are reference sites, located outside the Fore River.

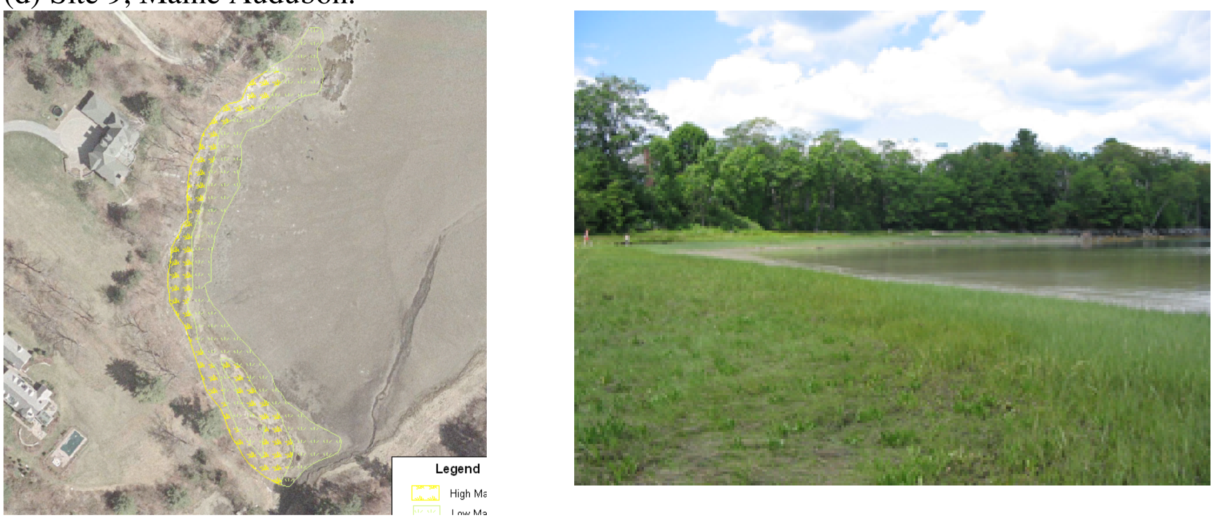
(a) Site F1, Mill Cove.

(b) Site F2, Pleasantdale Cove.

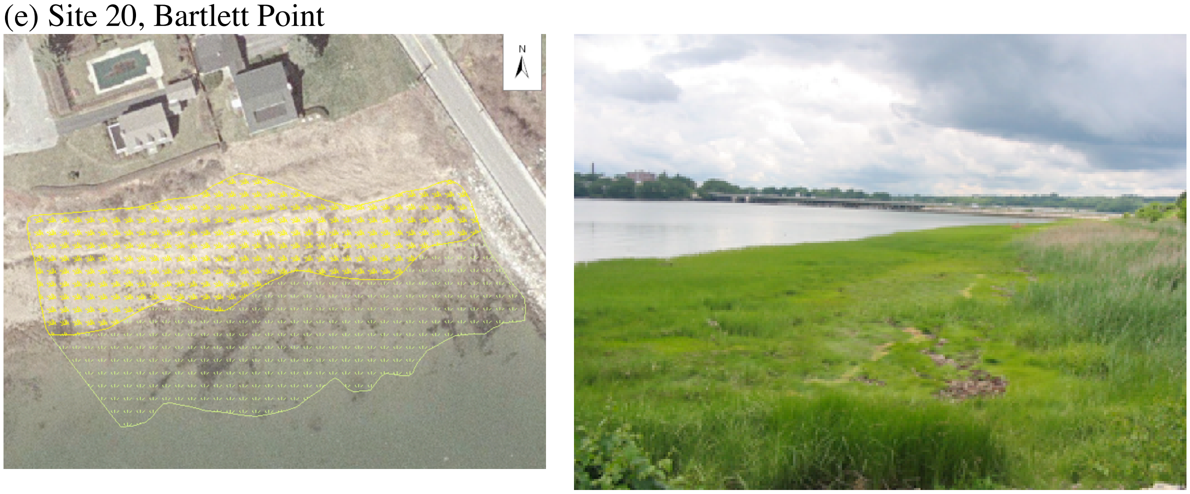
(c) Site F3, Stroudwater crossing.

Figure 2. Fringing marsh study sites. Photos on the left are aerial photographs, with marsh study sites indicated by an arrow or delineated with a yellow line. Photos of study sites on the right were taken in June 2004.

(d) Site 9, Maine Audubon.



(e) Site 20, Bartlett Point



(f) Site 29, Bayshore Road

Figure 2 (cont.). Fringing marsh study sites. Photos on the left are aerial photographs, with marsh study sites indicated by an arrow or delineated with a yellow line. Photos of study sites on the right were taken in June 2004.

Table 1. Fringing marsh study sites, 2004.

Site Number	Site Location	Site Name	Latitude/Longitude
F1	Fore River	Mill Creek, South Portland	Start point: 43.64068^0N 70.46589^0W End point: 43.63922^0N 70.45375^0W
F2	Fore River	Pleasantdale Cove, South Portland	Start point: 43.63419^0N 70.59402^0W End point: 43.63380^0N 70.62141^0W
F3	Fore River	Stroudwater Crossing, South Portland	Start point: 43.65789^0N 70.06117^0W End point: 43.65878^0N 70.08530^0W
9	Casco Bay, outside Fore River	Maine Audubon, Falmouth	Start point: 43.70758^0N 70.44853^0W End point: 43.70660^0N 70.45519^0W
20	Casco Bay, outside Fore River	Bartlett Point, Falmouth	Start point: 43.71265^0N 70.17809^0W End point: 43.71107^0N 70.17946^0W
29	Casco Bay, outside Fore River	Bayshore Road, Falmouth	Start point: 43.69462^0N 70.39505^0W End point: 43.69434^0N 70.40649^0W

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 two times at each site, once each in June and once in August. Means and standard errors for the nine data points sampled at each site were calculated.

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 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. 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).

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) in early August. 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. To compare Fore River sites to Casco Bay reference sites, we calculated the mean live aboveground biomass of the three sites along the river and compared this to the mean of the three reference sites. These means were then compared using ANCOVA, with elevation as a covariate.

Stem densities were also calculated from quadrats containing primarily *Spartina alterniflora* or *Spartina patens,* so that comparisons could be made with stem density data collected after the Julie N oil spill in 1996 and 1997 (Reilly 1998).

Invertebrates

Benthic invertebrates were sampled in June at a randomly located point in each vegetated zone (low marsh, high marsh and *Phragmites*, if present) of the six marsh sites. Three 7.8 cm diameter cores were taken at each of the sample points. The top 4 cm of substrate in 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 were analyzed. Each sample 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.

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).

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. The Casco Bay sites were sampled starting on the morning of June 6, and starting on the evening of August 27, 2004. The Fore River sites were sampled starting the morning of June 7 and starting the afternoon of August 25, 2004. 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 (Figure 3). 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. 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.

(a)

(b)

Figure 3. a) A fyke net deployed at a fringing marsh site. b) Retrieving a sample from a fringing marsh site.

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 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.

Species presence / absence was determined for each site for June and August separately, and compared to other Casco Bay sites sampled 2002 – 2004. Biomasses were determined separately for day and night sampling periods for each site. Biomass was also determined for each of four categories: total (fish plus crustaceans), fish, green crab, and shrimp. Area sampled was calculated separately for day and night periods, allowing separate day and night biomass densities to be determined at each site. These densities were then averaged for each site / month combination.

RESULTS and DISCUSSION

Physical characteristics of fringing 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 4. These elevations are not actual site elevations, but were measured relative to mean low tide. Site F3, which is located the furthest upstream in the Fore River, had a higher overall elevation than the other sites. This is reflected in its plant community, which was dominated by high marsh. Site F2, which had the lowest mean elevation, was dominated by low marsh. A more complete discussion of the plant and invertebrate communities at these fringing marsh sites will follow.

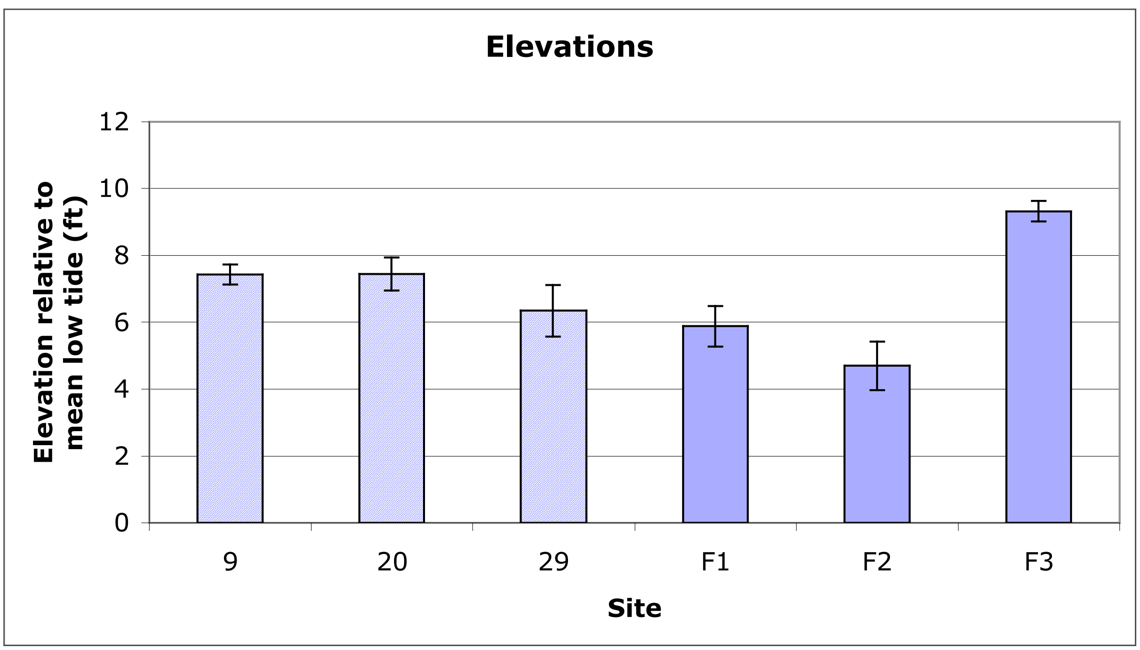


Figure 4. Mean elevations of fringing marsh sites, relative to mean low tide. Values are means of nine stratified random sample points on each site. Sites 9, 20 and 29 are Casco Bay reference sites, and sites F1, F2 and F3 are located in the Fore River. Bars are means ± 1 standard error.

Salinity

The soil porewater salinities of the nine sample sites are shown in Figure 5. Salinities did not vary much between the two sampling dates, one in June and one in August. Sites 9 (Maine Audubon) and F3 (Stroudwater) have lower salinities than the other sites, likely due to their locations farther from the open ocean.

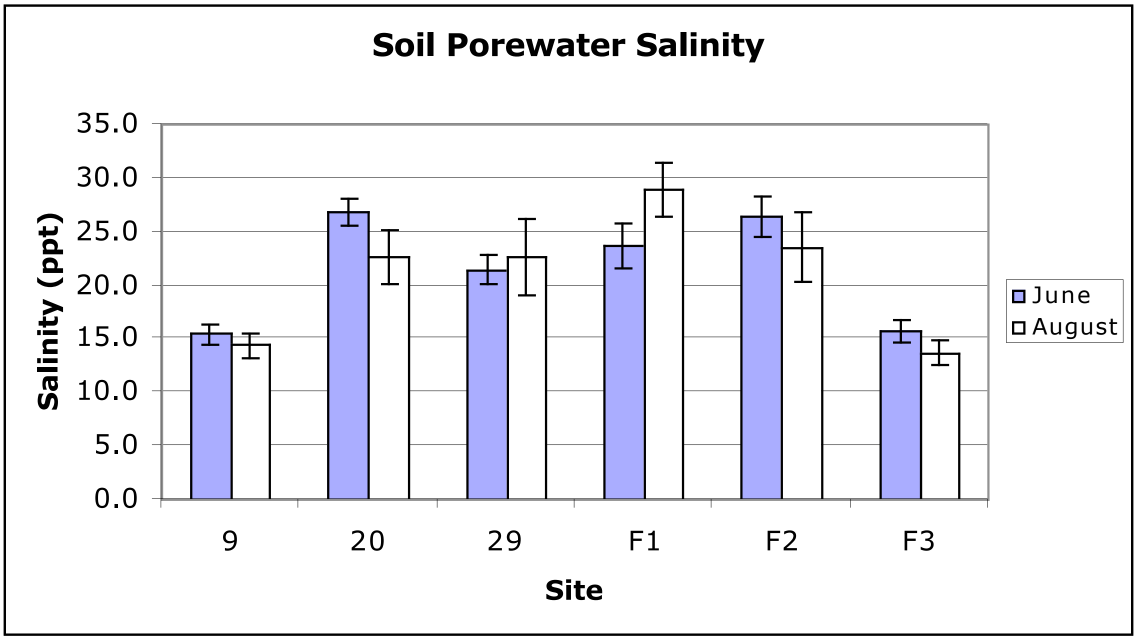


Figure 5. Average soil salinity of sites, determined from porewater extracted from marsh sediment in June and August. Bars are means ± 1 standard error.

Plant diversity

Fringing 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 sample quadrats at each of the six study sites is illustrated in Figure 6. Actual percent cover values are included in the Appendix. Two of the sites in the Fore River are predominantly low marsh, while the third (F3) is mostly high marsh. As mentioned earlier, site F3 had the highest elevation, which is why there is little *S. alterniflora* located there. Overall there was a difference in the total number of species found at the Fore River sites (average = 9 species per site) and at the Casco Bay reference sites (average = 14 species per site). This difference could be due to recent oil and other hydrocarbon spills that have occurred in the Fore River. Other studies have shown that oil spills can lower the number of species on a salt marsh in the following ways (Burger 1997, Scholten et al. 1987):

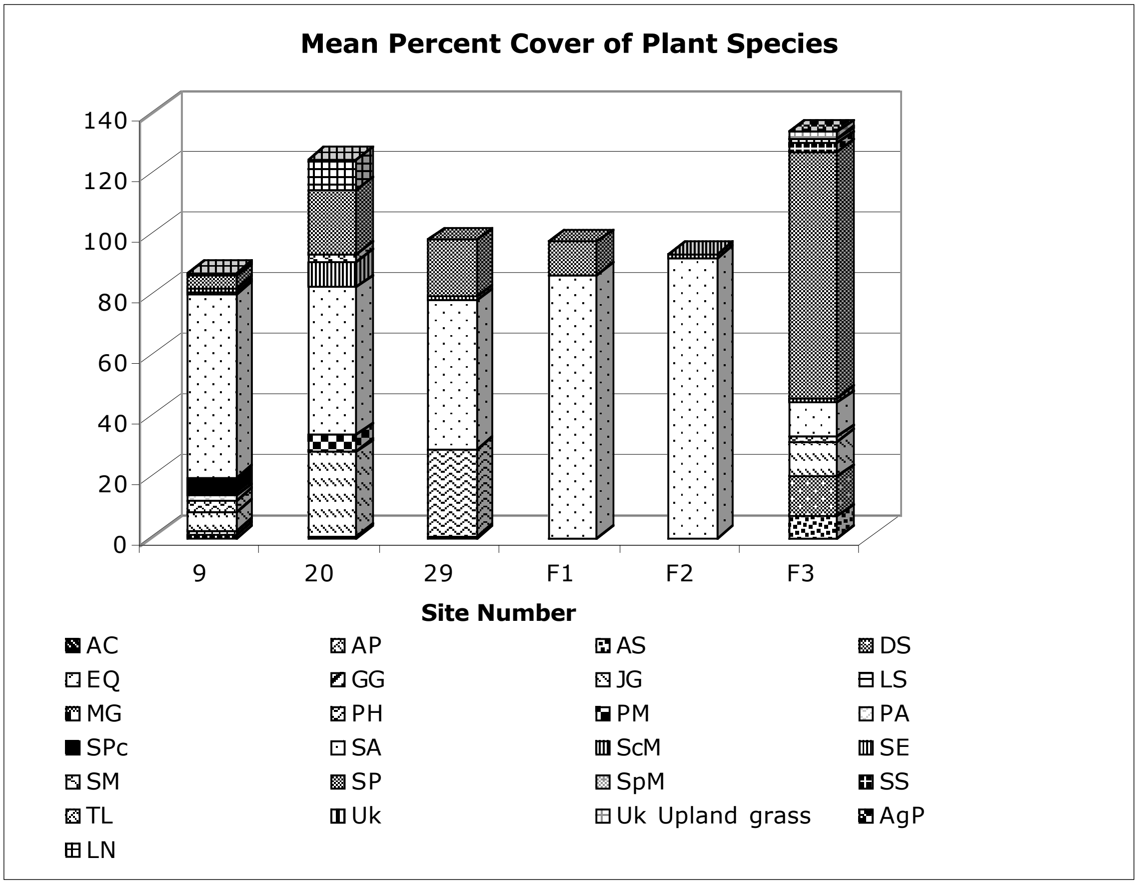


Figure 6a. Percent cover of plant species sampled at each fringing marsh site. AgP = *Agropyron pungens,* AP = *Atriplex patula,* GG = *Puccinellia maritima,* JG = *Juncus gerardii,* LN = *Limonium nashii,* PA = *Potentilla answerina,* PH = *Phragmites australis*, PM = *Plantago maritima,* SA = *Spartina alterniflora,* SE = *Salicornia europeae,* SM = *Sueda maritima*, SP = *Spartina patens,* Spc = *Spartina pectinata,* AC = *Amaranthus cannabinus*, AS = *Aster sp.*, DS = *Distichlis spicata*, EQ = *Equisetum sp.*, LS = *Lythrum salicaria*, MG = *Ipomoea sp.*, ScM = *Scripus maritima*, SpM = *Spergularia marina*, SS = *Solidago sempervirens*, TL =*Typha sp.*, Uk = Unknown species, Uk Upland grass = unknown upland species.

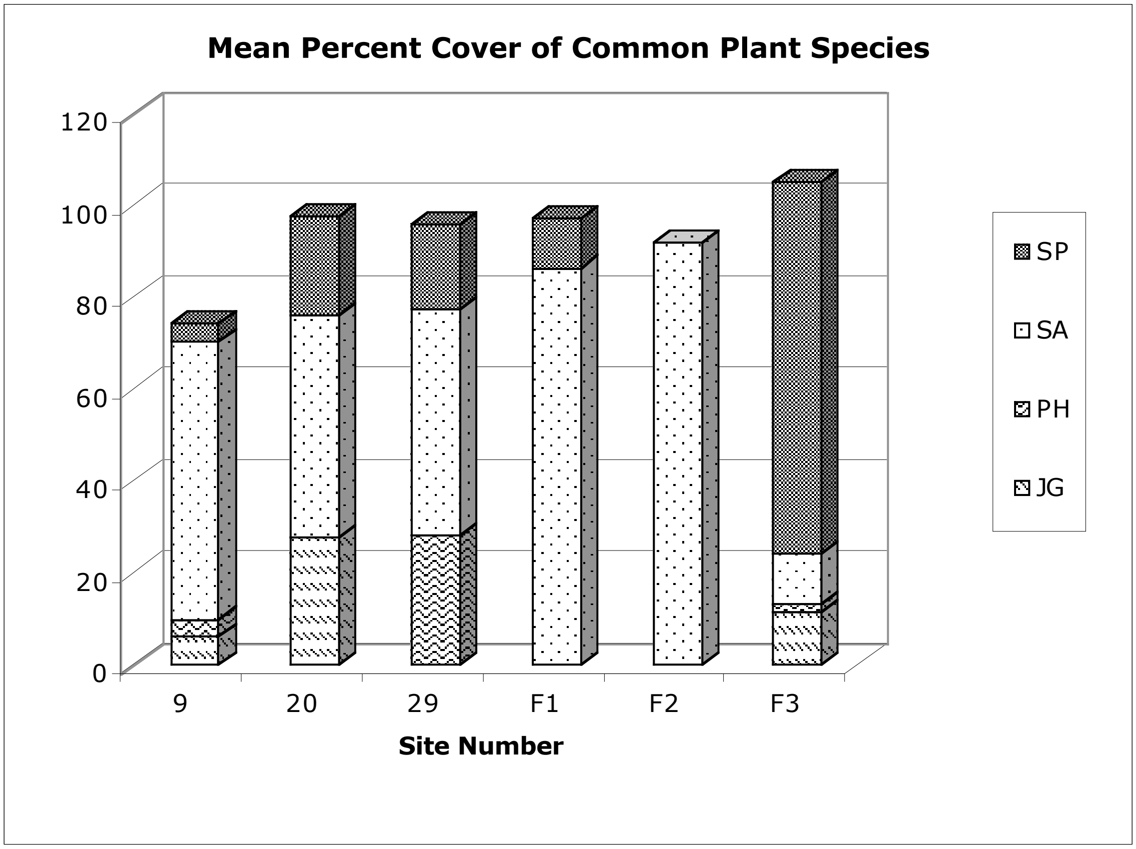


Figure 6b. Percent cover of most common plant species sampled at each fringing marsh site. SA = *Spartina alterniflora*, SP = *Spartina patens,* PH = *Phragmites australis,* JG = *Juncus gerardii.*

(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.

Table 2 shows several measures of diversity, including the Shannon-Weiner Index (H'), species richness (S), and evenness (E) for each of the sites studied. The total number of species column includes any species that were observed outside the sample quadrats, as well as those encountered in the sample quadrats. 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. The average Shannon-Weiner Index (H') at the Fore River sites and at the Casco Bay reference sites was significantly different when elevation was used as a covariate (ANCOVA, elevation $p = 0.0012$, location $p = 0.0035$) (Figure 7). This means that the Fore River sites are less diverse floristically that the reference sites, which could be a result of the recent oil spills.

Table 2. **Plant diversity values for six fringing marsh sites. H', S, E values are from nine quadrats per marsh site. Total number species observed value includes species seen outside of sample quadrats.**

Site	H'	S	E	Total no. species observed on marsh
9	0.611	14	0.533	19
20	0.709	9	0.743	9
29	0.542	6	0.697	13
F1	0.181	3	0.379	9
F2	0.051	3	0.107	4
F3	0.619	11	0.594	14

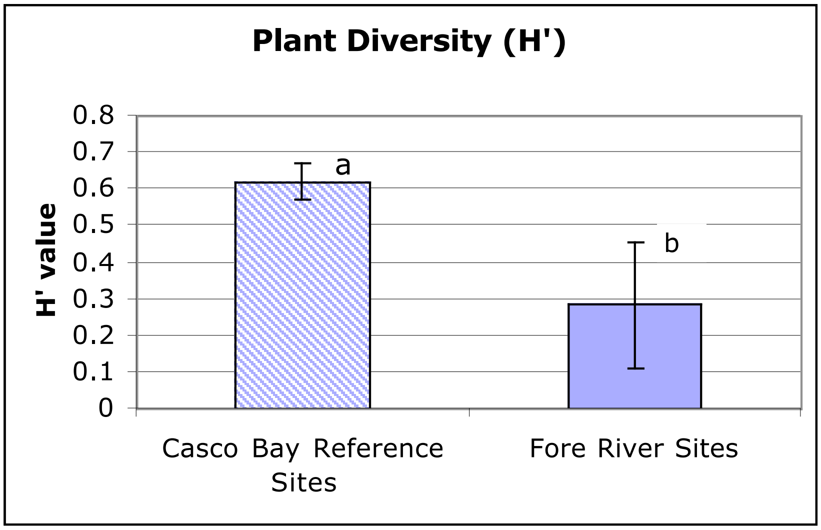
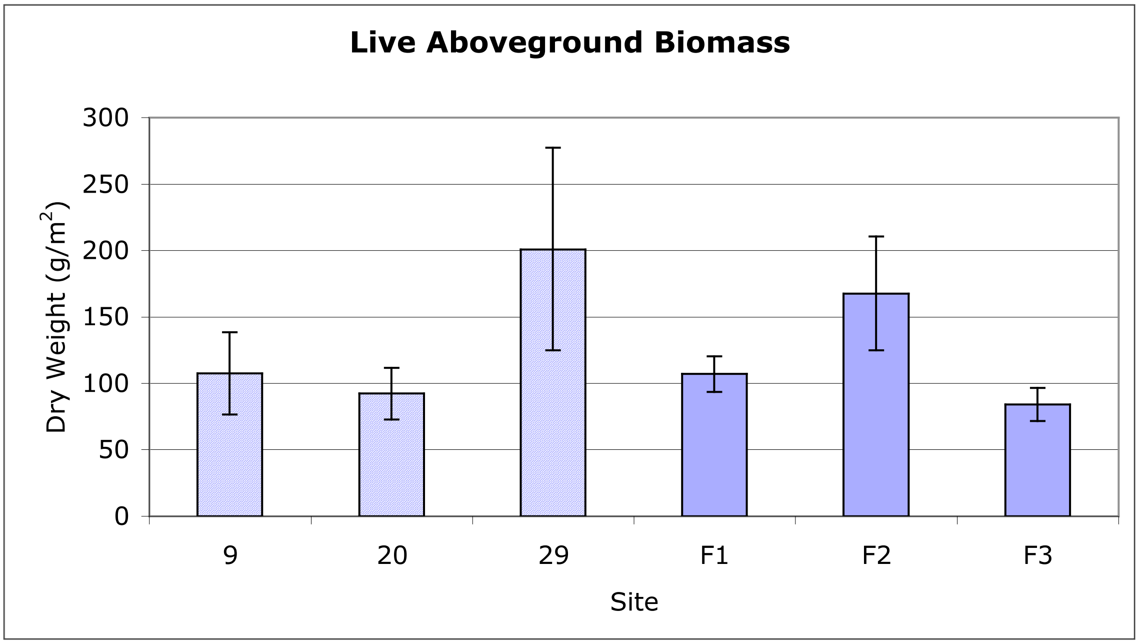


Figure 7. Mean Shannon-Weiner Index for Fore River and Casco Bay reference sites. Bars are means ± 1 standard error. Means are significantly different from one another (ANCOVA, elevation p = 0.0012, location p = 0.0035).

Aboveground production of marsh vegetation

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. Figure 8 shows that the mean aboveground production of these fringing marsh sites ranged between 84 – 201 g/m^2, which is consistent with values we have observed in Casco Bay in other years (Morgan et al. 2005). The Fore River marshes fall into this range, and in fact there was no statistically significant difference between the productivity of the Fore River sites and that of the Casco Bay reference sites in this 2004 study (ANCOVA, elevation p = 0.207, location p = 0.5636). Differences seen between sites in plant productivity likely reflect the different plant communities at the sites (e.g. a large part of site 29 is dominated by *Phragmites australis*), not the impact of past spill events. It therefore appears that the Fore River marshes, despite being impacted by oil and/or gasoline spills in recent years, have similar plant productivity compared to sites outside the Fore River. Other studies have found that the recovery of plants after a spill event can occur in a relatively short time (1-3 years) in some cases, but in other cases may take decades (Burger 1997).

The amount of dead aboveground biomass is sometimes measured following a spill event. The values we present here (Figure 8) fall within the range of values (3-30 g/m^2) we observed at Casco Bay fringing marsh sites in 2002 and 2003, and add to the baseline data we have collected for Casco Bay fringing salt marshes.



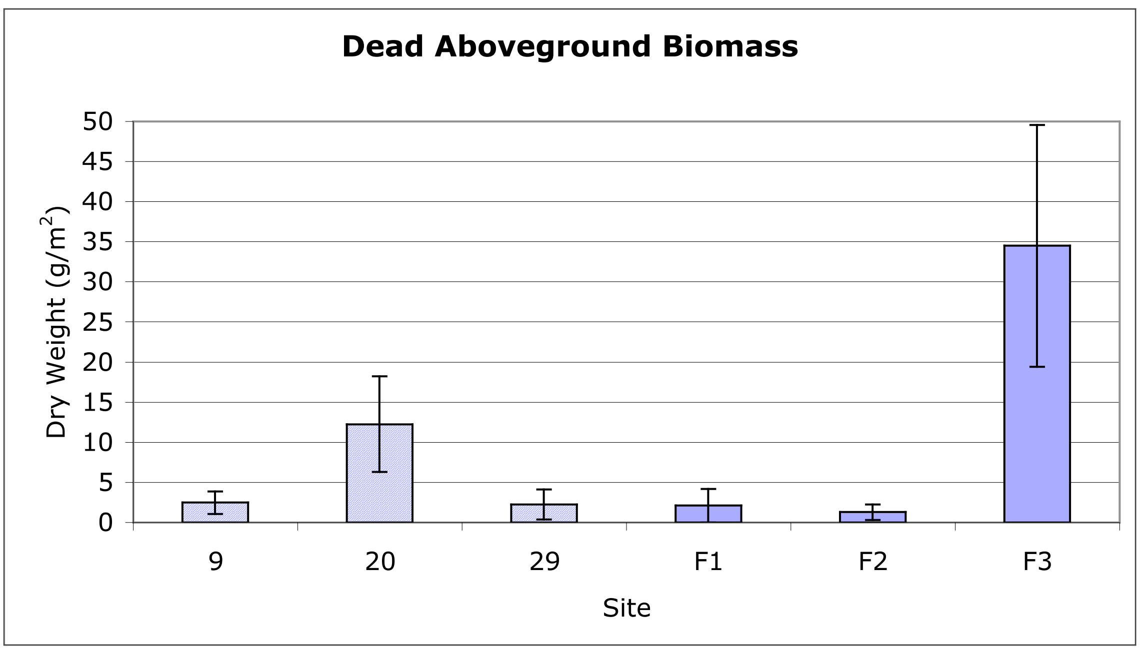


Figure 8. Mean live standing aboveground biomass and dead aboveground biomass at the end of the growing season at Casco Bay reference (9, 20, 29) and Fore River (F1, F2, F3) study sites. Bars represent means of nine stratifies random sample points ± 1 standard error.

We also calculated stem densities for *S. alterniflora* and *S. patens* in order to compare these results with what was observed at impacted sites after the Julie N oil spill, in 1996 and again in 1997. Four of the 12 transects surveyed in 96-97 fell within the marshes we

sampled – three in Mill Cove (our F1 site) and one at the Stroudwater marsh (our F3 site). The mean *S. alterniflora* stem density we measured in 2004 at the Fore River sites was 26 stems per 1/16 m^2, compared to a range of values in 1996 of 15-32 stems per 1/16 m^2 and in 1997 of 17-38 stems per 1/16 m^2. *S. alterniflora* stem density therefore appears to be consistent from 1996 to the present, although it should be noted that in the 1996-97 survey, researchers recorded *S. alterniflora* short and tall in separate categories, whereas we did not distinguish between these two forms, seeing primarily *S. alterniflora* tall. *Spartina patens* stem density was recorded only at the Stroudwater site in 1996 (range of 270-325 stems per 1/16 m^2). We observed *S. patens* at a density of 145 stems per 1/16 m^2 at this site in 2004.

Invertebrates

Invertebrates collected at the study sites were identified to the lowest taxonomical level possible, often to the species level. More than twenty different species and numerous additional taxa of intertidal invertebrates were identified at the six fringing marshes investigated in this study. The density of invertebrates in the low and high marsh areas at these sites ranged from approximately 4,000 – 54,000 individuals per square meter. On average, the low marsh zone contained higher densities of invertebrates (~32,000 indivs/m^2) than the high marsh zone (~16, 500 indivs/m^2). Densities in marsh areas dominated by *Phragmites australis* were much less (~2,000 indivs/m^2). Figure 9 shows the densities of invertebrates in the different vegetated zones at the six marsh sites. In addition, the Fore River sites appear to have lower densities of invertebrates in the low marsh zone than the Casco Bay reference sites (Figure 10). This could be due to contamination by recent spills over the past decade affecting the Fore River and its tributaries.

Elevated levels of hydrocarbons in salt marsh sediments may cause mortality of existing invertebrate species and make space available to tolerant opportunistic invertebrate species, such as the early colonizing *Nereis* and *Hydrobia* (Atkinson 2004, Levell et al. 1989, Hiscock 2004). We were interested in seeing if there were differences in the kinds and numbers of invertebrates present in the Fore River salt marshes compared to sites outside of the Fore River. Figure 11 shows the individual classes of invertebrates found at the different sites and their relative densities. We observed no difference between Fore River and Casco Bay reference sites for many classes of invertebrates. Arachnida were found at all the sites at low densities with the exception of site 9, which contained greater numbers of these organisms (Figure 11a). Bivalve densities did not show any trends across the different sites (see figure 11b), but one particular bivalve, the soft-shelled clam *Mya arenaria*, was observed at only one reference site (site 9) and nowhere in the Fore River sites. Spill events elsewhere have been documented as having negative impacts on soft-shelled clam communities (Hiscock et al. 2004). Insect densities appear to be similar across all sites (Figure 11c), and aside from a greater number of insect larvae at site 9, densities of insect larvae were also similar across all of the study sites (Figure 11d). Oligochaete and polychaete densities, although varying from site to site, showed no differences between Fore River and Casco Bay reference sites (Figures 11e, f).

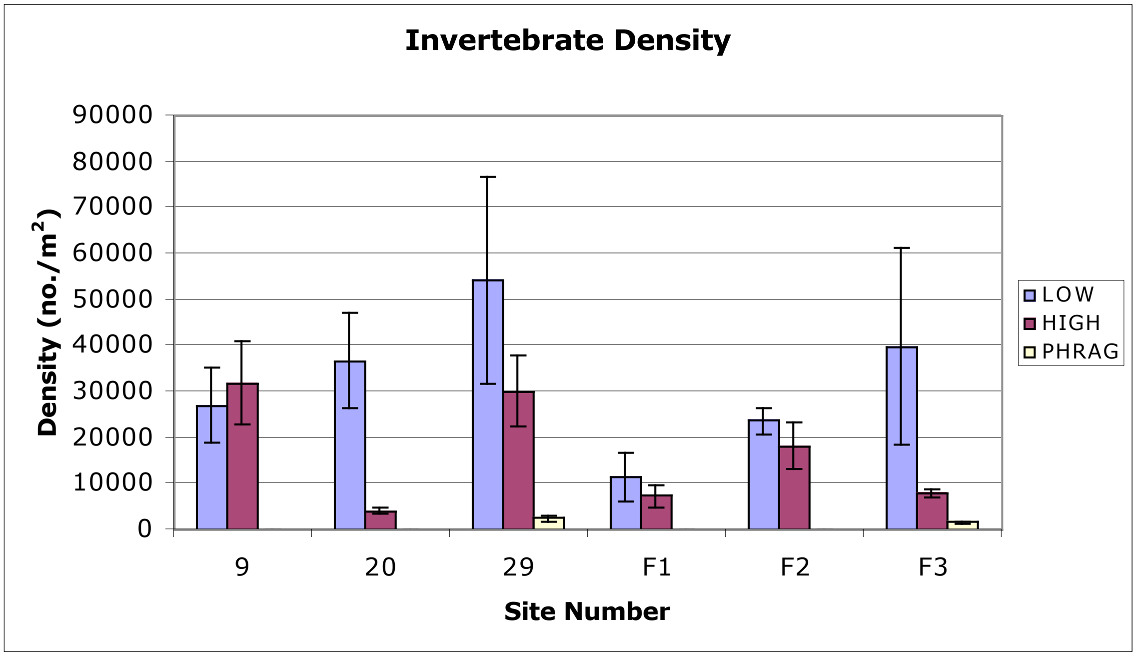


Figure 9. Average densities of invertebrates in the upper 4 cm of Fore River and Casco Bay reference fringing marsh soils. Samples were taken from 7.8 cm diameter cores in low marsh, high marsh and *Phragmites* areas of fringing marsh sites.

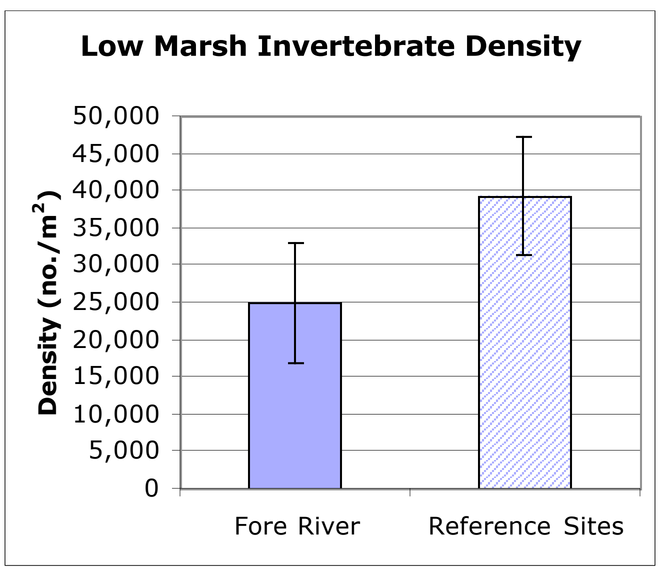


Figure 10. Invertebrate density in the upper 4 cm of low marsh soil in Fore River and in Casco Bay reference sites. Bars are means of three sites, with standard errors.