

The Functions and Values of Fringing Salt Marshes in Northern New England, USA

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Abstract We compared the functions and values of fringing salt marshes to those of meadow marshes along the southern Maine/New Hampshire coast. Differences included soil organic matter content, plant species richness, and percent cover of high and low-marsh species. More sediment was trapped per unit area in fringing marshes than in meadow marshes, but this difference was not significant. Similarities included aboveground and belowground peak season biomass and the ability to dampen wave energy. Both marsh types reduced the height of waves coming onto the marsh surface by 63% only 7 m into the marsh. Fringing marshes are diverse in terms of their physical characteristics (width, length, slope, elevation, soils). Despite their small size, they are valuable components of estuaries, performing many ecological functions to the same degree as nearby meadow marshes. More effort should be made to include them in regional efforts to conserve and restore coastal habitats.

Keywords Fringe marsh · Meadow marsh · Vegetation · Gulf of Maine

Introduction

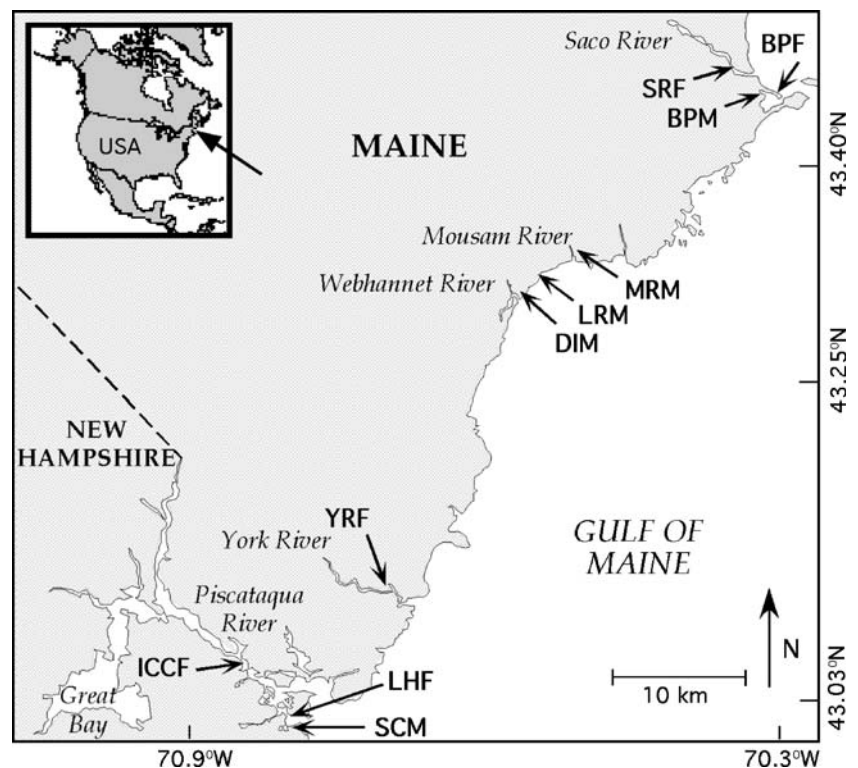
Our current understanding of salt marsh ecology comes from studies of large marsh systems, especially those along the Eastern coast of the US. These salt marshes typically have a distinct zonation of plant communities, which reflects their surface elevation and the effects of tidal flooding (Miller and Egler 1950; Niering and Warren 1980). They are valued for a number of reasons, including their role as nursery grounds for finfish and shellfish, their ability to accrete sediments and counter the effects of sea-level rise, their role in storm surge protection, and their recreational and aesthetic values (Teal 1986; Short et al. 2000). However, many of the salt marshes that line the edges of bays and rivers are quite narrow in width and small in size (Roman et al. 2000). Despite the fact that they are a common habitat type, little is known about the ecology or the functions and values of fringing salt marshes. Studies have examined the role that fringing salt marshes may play as transformers of nitrogen that enters the estuary from adjacent uplands (Lyons et al. 1995; Tobias et al. 2001; Davis et al. 2004), but other aspects of fringing marsh ecology have been studied little or not at all.

Fringing salt marshes are in need of study not just because of the paucity of information available about them but also because they are particularly susceptible to environmental impacts. On their landward borders, they are often abutted by residential and commercial development, and on their seaward borders they are exposed to the erosive force of waves. Because they are narrow, impacts to the borders of a fringing marsh have proportionately large effects on the entire marsh. Also because they are narrow, fringing marshes provide convenient access to open water for fishermen and boaters, who may impact them unintentionally.

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Fig. 1 Locations of fringing salt marsh and meadow salt marsh study sites. Complete site names and locations (latitude/longitude) are listed in Table 1. Sites ending in *F* are fringing marshes; sites ending in *M* are meadow marshes



The purpose of this study was to compare the functions and values of fringing salt marshes to those of larger meadow salt marshes and, in some cases, to shoreline areas where no marsh was present. We also aimed to determine how marsh physical characteristics (size, elevation, surface slope, and soil salinity) are related to selected marsh functions. Based on past experience and the scientific literature, we developed a list of the functions and values of New England's salt marshes (Short et al. 2000) and then selected several of these for study in salt marshes in southern Maine and New Hampshire. Functions selected included primary production, soil organic matter accumulation, filtration/trapping of sediments, maintenance of plant biodiversity, and dissipation of physical forces of waves.

Materials and Methods

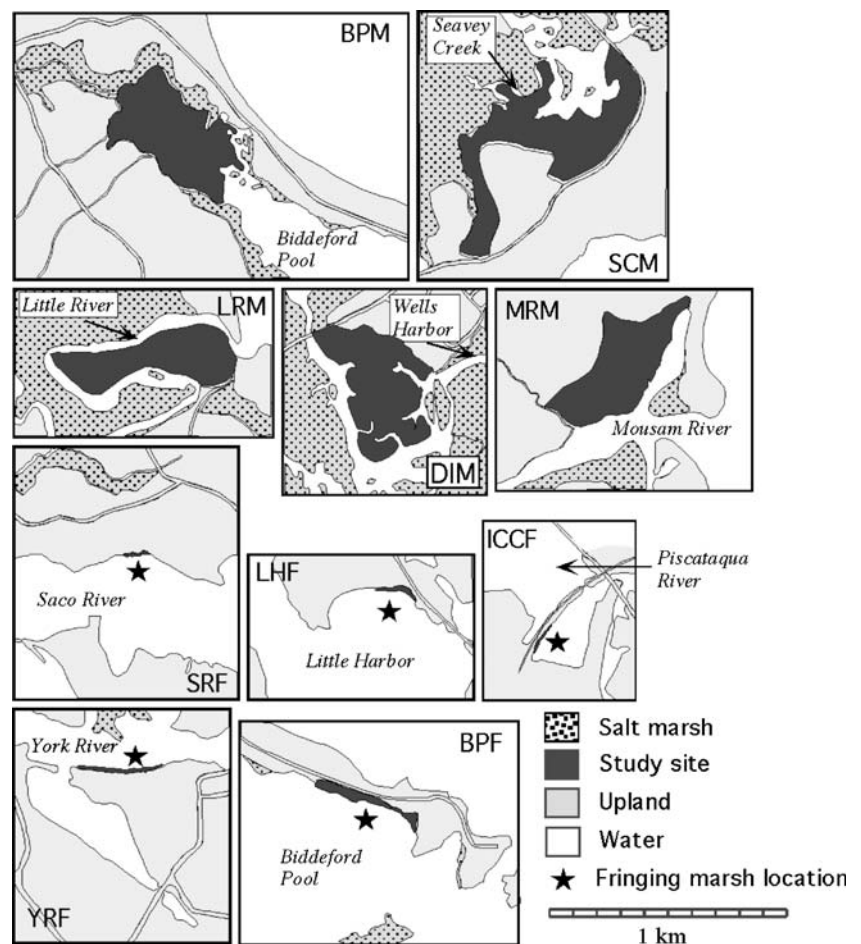
Five fringing marshes and five meadow marshes were selected for study from the Saco River, Maine, south to the Great Bay Estuary in New Hampshire (Fig. 1; Table 1). The mean tidal range within the area is approximately 2.7 m, with semi-diurnal tides. The fringing marshes chosen are all located along the edges of rivers, bays, or coves, and the meadow marshes are found behind barrier beaches (Fig. 2). All of the meadow marshes are naturally divided into sections by large creeks or rivers, so we selected one of these sections for study in each meadow marsh.

Nine sample stations were established on each marsh site using a stratified random sampling design, according to the proportion of high-marsh area to low-marsh area. Physical

Table 1 Locations of fringing salt marsh and meadow salt marsh study sites

Site name	Marsh type	Location	Latitude/longitude
SRF	Fringing	Saco River, Biddeford, ME	43° 24' 24" N/70° 32' 29" W
BPF	Fringing	Biddeford Pool, Biddeford, ME	43° 26' 58" N/70° 21' 51" W
YRF	Fringing	York River, York, ME	43° 8' 10" N/70° 39' 13" W
ICCF	Fringing	Inner Cutts Cove, Portsmouth, NH	43° 5' 8" N/70° 45' 59" W
LHF	Fringing	Little Harbor, Rye, NH	43° 3' 21" N/70° 43' 53" W
BPM	Meadow	Biddeford Pool, Biddeford, ME	43° 27' 15" N/70° 22' 29" W
MRM	Meadow	Mousam River, Kennebunk, ME	43° 20' 49" N/70° 30' 39" W
LRM	Meadow	Little River, Wells, ME	43° 20' 24" N/70° 32' 39" W
DIM	Meadow	Drake's Island, Wells, ME	43° 19' 37" N/70° 33' 46" W
SCM	Meadow	Seavey Creek, Rye, NH	43°2'53"N/70°43'25"W

Fig. 2 Relative sizes of five meadow and five fringing salt marsh sites (all shown at the same scale). Study sites are *dark gray*; surrounding salt marshes are *stippled gray*



data (pore water salinity, surface elevation, surface slope) and biological data (primary productivity, soil organic matter accumulation, and plant diversity) were then collected at these sample stations.

Physical Characteristics of Marsh Study Sites

Soil pore water salinity was determined in July and August with a temperature-corrected optical refractometer after extracting water from 10- to 15-cm depth with a soil sipper. Elevations of all sample locations were determined using a Meridian L6-20 level and stadia pole and then tied into the 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 marsh site on a windless day, after which the high tide (3.63-m mean higher high water) left a distinct line. Surface slope was measured at each sample station in a direction perpendicular to the water's edge, across a horizontal distance of 1 m. The area of each site was determined with National Institutes of Health Image 1.47, from the

US Geological Survey topographic maps, aerial photographs (1 cm=24 m), and field measurements.

Means and standard errors of the nine data points for each of the physical characteristics above were calculated for each marsh site and compared using analysis of variance (ANOVA). Pairwise comparisons were made with Student–Newman–Keuls or Scheffé's *S* tests, as appropriate. The overall means and standard errors for meadow and fringing marsh types were also determined and compared using ANOVA.

Ecological Functions of Marsh Study Sites

Five salt marsh functions at each of the ten salt marsh sites were evaluated using a variety of indicators, each developed based on knowledge of the literature and previous experience. These indicators were measured in the field using methods summarized in Table 2. When sediment accumulation on the marsh surface was measured, additional data collected included the number of plant stems and the percent cover of plant species present in a 1-m² quadrat around sediment traps as well as the suspended sediment concentration in the water flooding the marsh surface. The

Table 2 Salt marsh functions studied and corresponding indicators assessed at fringing and meadow salt marsh sites

Function [value]	Indicator	Method	Reference
Primary production [support of food webs, fisheries and wildlife]	Annual standing crop (above and belowground biomass/area/time)	Random clip plots (0.25 m ²), live plants separated and dried at 60°C	Morgan and Short (2002)
		Sediment cores (20 cm deep, 3.5 cm diameter), live roots and rhizomes separated and dried at 60°C	Gross et al. (1991)
Soil organic matter accumulation [support of food webs, counter sea-level rise]	Accretion + soil percent organic matter (mass/area)	Cores (15 cm deep, 3.5 cm diameter) Loss on ignition determined in muffle furnace at 450°C for 4 h	Craft et al. (1991)
Maintenance of plant diversity [support of biodiversity, provide animal habitat]	Species richness, relative abundance (no. species/site, percent cover of plant species)	Percent cover by species in 1-m ² plots estimated visually using 0%, 0%<x≤1%; 1%<x≤5%; 5%<x≤10%; 10%<x≤20%; and continuing above 20% in 10% increments up to 100%. Total percent cover per quadrat did not exceed 100%	Morgan and Short (2002)
Sediment filtration and trapping [counter sea-level rise, improve water quality]	Sediment accumulation on discs (sediment mass/area/time)	Mylar discs (8 cm diameter) pinned to sheet metal plates and stapled to marsh surface; sediment accumulated over 10-day period in mid-August; discs dried at 60°C for 48 h	Reed (1989)
		5 traps randomly distributed; five traps placed 1 m from water's edge 3 traps in areas of no marsh, adjacent to five fringing marsh sites	Morgan and Short (2002)
Wave and current energy dampening [protect upland from erosion, reduce flood- related damage]	Video-generated wave profiles (reduction in wave height/distance from marsh edge)	Waves generated by boat and then heights filmed and measured along three transects at 0, 5, and 7 m from marsh's seaward edge Measured at three fringing marsh sites, three meadow marsh sites, and three areas where no marsh was present	N/A

number of quadrats sampled to determine plant diversity was based on preliminary sampling and calculation of running averages for small and large marsh sites. The minimum number of quadrats needed to include the majority of plant species on fringing and meadow marsh sites was ten and 30, respectively. These quadrats were then distributed in a stratified random manner, according to the proportion of high and low marsh at each site.

To assess how well fringing and meadow marshes dissipate wave energy, we measured the difference between wave heights at the marsh/water edge and 5 and 7 m into the marsh, along three transects perpendicular to the water's edge. Waves were generated by the wake of a 5-m aluminum boat and then videotaped in front of a meter stick simultaneously at 0 and 5 m, then at 0 and 7 m. Videotapes were later viewed frame by frame (30 frames per second) and wave peaks and troughs were recorded for each take at 0 m and at 5 or 7 m. The maximum trough to peak height was determined for each take, as were the two wave heights following the maximum wave. The percent

reduction in maximum wave heights from 0 to 5 m and from 0 to 7 m was calculated for three takes at each transect and then averaged. The mean height of three waves (maximum and two following) per take was also calculated and then the percent reduction in this "three-wave mean" height was determined from 0 to 5 m and from 0 to 7 m. Percent wave height reduction values (maximum and three waves) obtained for the three transects were then averaged to determine means for each fringing marsh, meadow marsh, and "no-marsh" site. In addition, the depth of the water at the time of filming was also recorded at the 0-, 5-, and 7-m points along transects. We surveyed wave reduction at three fringing marsh sites, three meadow marsh sites, and three areas where no marsh was present.

Before comparing fringing marsh and meadow marsh functions, the possible relationships between each of the functions and the physical characteristics measured at the sites were explored. Previous studies have shown that the physical characteristics of salt marsh sites can influence their ecological functions (e.g., Jacobson and Jacobson 1989; Knutson et al.

1982; Kastler and Wiberg 1996). Scatter plots were drawn comparing the quantitative assessment for each function with each of the physical characteristics investigated for that function, and correlation coefficients were calculated for each function–physical characteristic pair. Results of these correlations aided in the choice of variables to use as covariates in the means comparisons described below.

For each of the functions in Table 2 and their associated metrics, means and standard errors of the five fringing marshes and the five meadow marshes were calculated. Means were also calculated for the areas where no marsh was present when assessing sediment filtration and trapping and the dissipation of wave energy. ANOVA or analysis of covariance (ANCOVA) was then employed to compare mean values.

Results

Physical Characteristics of Marsh Study Sites

Soil pore water salinity, surface elevation, marsh area, and distance to the water's edge of sample points were all significantly less in fringing salt marshes than in meadow marshes (calculated as means of five sites; $p < 0.05$; Fig. 3a–d). However, surface slope was significantly greater in fringing marshes than in meadow marshes ($p < 0.01$; Fig. 3e). To see how each marsh contributed to these differences, Fig. 3 also shows means and standard errors of the nine samples at each marsh site.

Comparison of Fringing Marsh Functions to Meadow Marsh Functions

Primary Production

We found no difference in the production of aboveground or belowground biomass between fringing and meadow marshes (Fig. 4). The slope of the marsh surface may affect productivity in fringing marshes, as it was highly correlated with both aboveground ($r = 0.941$, $p < 0.05$) and belowground ($r = 0.951$, $p < 0.05$) biomass.

Soil Organic Matter Accumulation

The organic matter content of meadow marsh soils was significantly greater than that of the fringing marsh soils (Fig. 5a). The five fringing marsh sites had lower surface elevations than the five meadow marshes, and two were significantly lower in elevation (Fig. 3g). Soil percent organic matter content was discovered to correlate with marsh surface elevation ($r = 0.801$, $p < 0.05$; Fig. 5b), and, in an ANCOVA of marsh type and elevation, organic matter in meadow marsh

soils was greater than that in fringing marsh soils, even after the variability due to elevation was accounted for ($F = 8.936$, $p = 0.020$; elevation covariate $F = 28.540$, $p = 0.0011$).

Sediment Filtration and Trapping

Although there was on average more sediment deposited on the traps randomly distributed on the surface of the fringing marshes than on the surface of the meadow marsh sites, this difference was not significant (Fig. 6a). Areas where no marsh was present had an even greater amount of sediment deposited per unit area. However, the variance around the mean was extremely high for “no-marsh” areas, with the standard deviation (6.84) greater than the mean ($4.24 \text{ g m}^{-2} \text{ day}^{-1}$). A comparison of the means for meadow, fringing, and “no-marsh” areas showed no significant difference in the amount of sediment deposited on these three site types, even after removing the variance associated with elevation, which was a significant covariate in the model ($F = 1.077$, $p = 0.374$, log-transformed data; elevation covariate $F = 22.385$, $p = 0.0006$). Sediment deposition was less at sites with a higher mean elevation, at both fringing and meadow marsh sites.

Traps placed just 1 m in from the edge of the marsh sites collected more sediment than those that were distributed randomly, as expected. Once again, there was no significant difference in the mean amount of sediment deposited on fringing, meadow, and “no-marsh” sites, even if the variability due to elevation was removed ($F = 1.077$, $p = 0.374$, log-transformed data; elevation covariate $F = 5.857$, $p = 0.034$; Fig. 6b). One trap at site DIM had an unusually large amount of sediment deposited on it ($1,847.89 \text{ g m}^{-2} \text{ day}^{-1}$, compared to the next highest value of $0.92 \text{ g m}^{-2} \text{ day}^{-1}$). This was attributed to the presence of a nearby culvert, which greatly increased the velocity of the water moving through the area, most likely causing large amounts of sediment to be resuspended and deposited. This data point was therefore considered an outlier and was discarded.

We had expected that suspended sediment concentration of the tidal water moving onto the marsh surface would influence the amount of sediment deposited on the sediment traps, but this is not what we observed in meadow marshes (Fig. 7). Although significant in fringing marshes, the relationship in Fig. 7 is driven by observations at a single site ($r = 0.999$, $p < 0.001$). We did find that vegetative cover may influence the amount of sediment deposited on the marsh surface, however. The greater is the percent cover of plants around sediment traps, the less is the amount of sediment deposited ($r = -0.732$, $p < 0.05$).

Maintenance of Plant Communities

Most measures of plant diversity differed between fringing and meadow marshes (Table 3). Species richness, species

density, and the percent cover of dominant high-marsh plants (*Spartina patens*, *Juncus gerardii*, *Distichlis spicata*, and *Puccinellia maritima*) was greater in meadow marshes, whereas the percent cover of the low-marsh species, *Spartina alterniflora*, was greater in fringing marshes. The Shannon–Weiner Index (H') and evenness (E) were similar in the two marsh types. Calculation of these two diversity indices was based on ten randomly selected quadrats per site.

Dissipation of Physical Forces of Waves

An example of the wave profiles generated from videotaping passing waves at 0 m (the marsh edge) and at 5 m can be seen in Fig. 8. Along all transects at all sites, the heights of the largest waves at 0 m ranged from 3.5 to 27.3 cm, averaging 12 cm tall. The “three-wave mean” height (mean height of the maximum and next two waves) at 0 m ranged from 2.7 to 21.2 cm, with an average of 7.8 cm.

The waves used to calculate percent height reductions along each transect were not shallow water waves. We determined this by measuring wavelengths of suspect waves on the video screen and comparing them to water depths at those points. The water depth was always significantly greater than 1/20 of the wavelength (Denny 1988).

In both fringing and meadow marshes, the heights of the largest waves traveling 7 m across the marsh surface were reduced by more than 60% (Fig. 9a). Where no marsh was present, wave heights were reduced by only 33%. This difference was statistically significant ($F=5.642$, $p=0.042$, square-root-transformed data). The percent reduction in wave height across 7 m was less when we considered the “three-wave mean” height: 55% in fringing and 52% in meadow marshes, compared to 28% in “no-marsh” areas ($F=4.90$, $p=0.055$, log-transformed data; Fig. 9b).

Discussion

Physical Characteristics of Fringing and Meadow Marsh Study Sites

In general, fringing marshes are narrower, steeper, and have lower mean surface elevations than meadow marshes. They are also more variable than meadow marshes in terms of their elevations and surface slopes (Fig. 3). This variability is an important property of fringing salt marshes, in part because elevation and slope may influence marsh function. In addition, their variability makes it difficult to describe a “typical” fringing salt marsh. Although the fringing marsh soils had statistically lower mean pore water salinity than

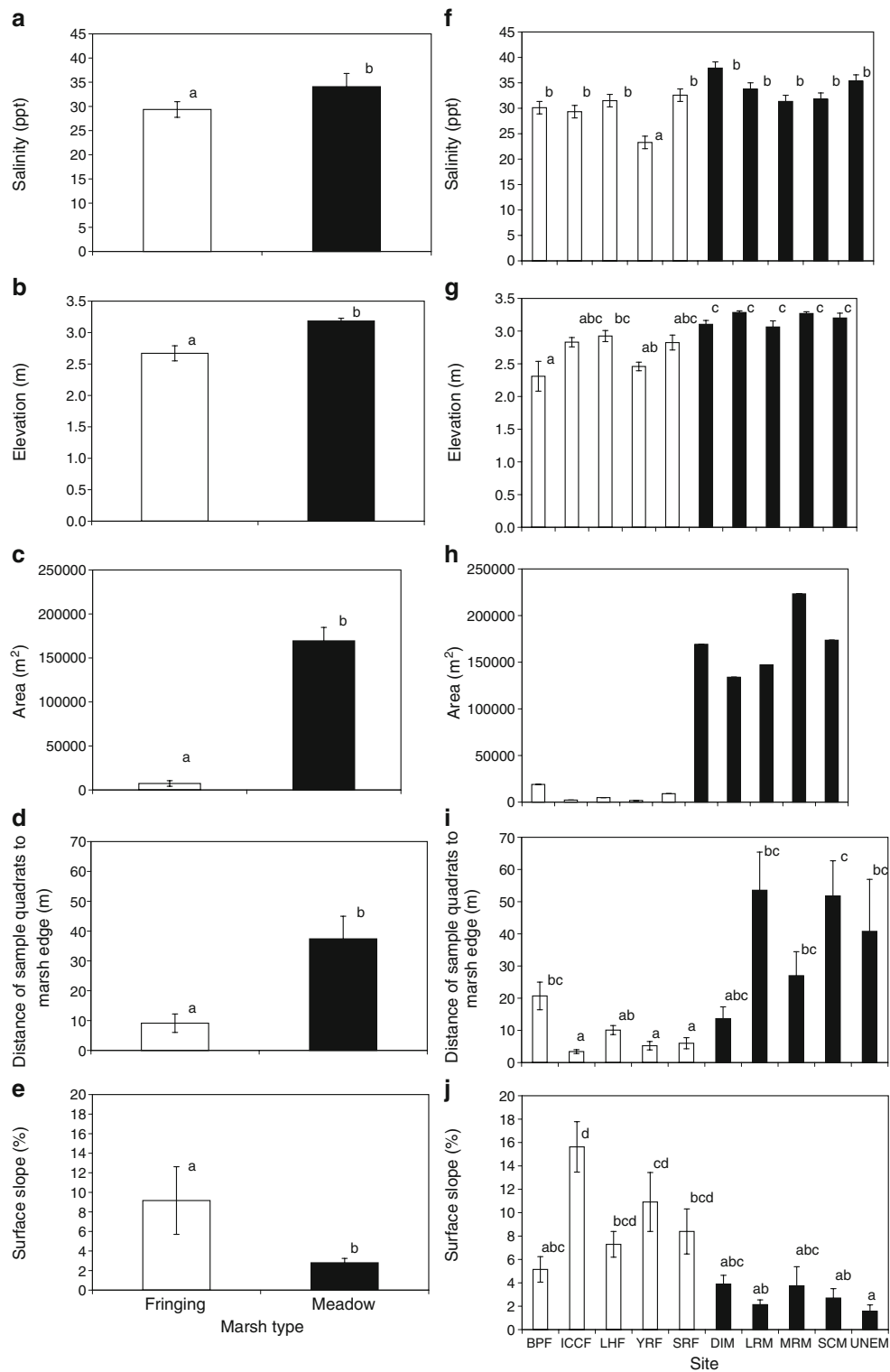
Fig. 3 Means of physical characteristics for each marsh type and for sample points at each site. Bars in each graph followed by the same letter are not significantly different from each other according to the pairwise comparison listed. Error bars are ± 1 SE. **a** Mean pore water salinities of five fringing marsh and five meadow marsh sites. Means are significantly different from each other ($F=5.417$, $p=0.048$). **b** Mean elevations of five fringing marsh and five meadow marsh sites. Means are significantly different from each other ($F=16.155$, $p=0.004$). Elevation units are meters above 0-m tide. **c** Mean areas of five fringing marsh and five meadow marsh sites. Means are significantly different from each other ($F=172.007$, $p=0.0001$, square-root-transformed data). **d** Mean distance from water’s edge to nine sample quadrats at five fringing marsh and five meadow marsh sites. Means are significantly different from each other ($F=14.114$, $p=0.006$, log-transformed data). **e** Mean surface slope of five fringing marsh and five meadow marsh sites. Means are significantly different from each other ($F=23.834$, $p=0.0012$, log-transformed data). **f** Pore water salinities at each site. Means are significantly different from each other ($F=4.114$, $p=0.0003$). Pairwise comparisons made with Student–Newman–Keuls (SNK). **g** Elevations at each site. Means are significantly different from each other ($F=10.931$, $p=0.0001$). Pairwise comparisons made with Scheffe’s S . Elevation units are meters above 0-m tide. **h** Areas of fringing and meadow marsh sites. **i** Mean distance from water’s edge to nine sample quadrats at each site. Means are significantly different from each other ($F=7.459$, $p=0.0001$, log-transformed data). Pairwise comparisons made with SNK. **j** Percent surface slope at each site. Means are significantly different from each other ($F=6.393$, $p=0.0001$, log-transformed data). Pairwise comparisons made with SNK

the meadow marshes, this difference was primarily due to the very low soil salinity at one fringing marsh site (Fig. 3a, f). We found no strong correlations between salinity and any of the functions we studied.

Comparison of Fringing Marsh Functions to Meadow Marsh Functions

Primary Production

Our results demonstrate that the primary productivity of fringing marshes is as great as that of meadow marshes, indicating that they are important contributors to estuarine food webs. Mean aboveground production in fringing marshes was similar to that in meadow marsh sites, and, although the mean belowground production in meadow marsh sites was greater than that in fringing marsh sites, this difference was not significant. Although harvesting the peak season standing crop is a commonly used method measuring aboveground production, it underestimates true aboveground net production by 10–15% (Nixon and Oviatt 1973). Comparing the aboveground biomass values we obtained to those of other studies is difficult because of the variety of sample methods that have been employed to measure aboveground production (Marinucci 1982). Nevertheless, our values are within the range of those found in studies of other Maine and New Hampshire salt marshes (Lindthurst and Reimold 1978; Gross et al. 1991).



Studies of salt marsh belowground biomass production are few in number compared to studies of aboveground biomass production due to the difficulty of sampling and processing belowground tissues (Gross et al. 1991). However, investigating the belowground component of

production is important, as it can be four to seven times greater than that of aboveground production (Marinucci 1982). The belowground to aboveground biomass ratio was 4.8 in the fringing marshes we sampled and 6.9 in the meadow marshes. Also, our values for belowground

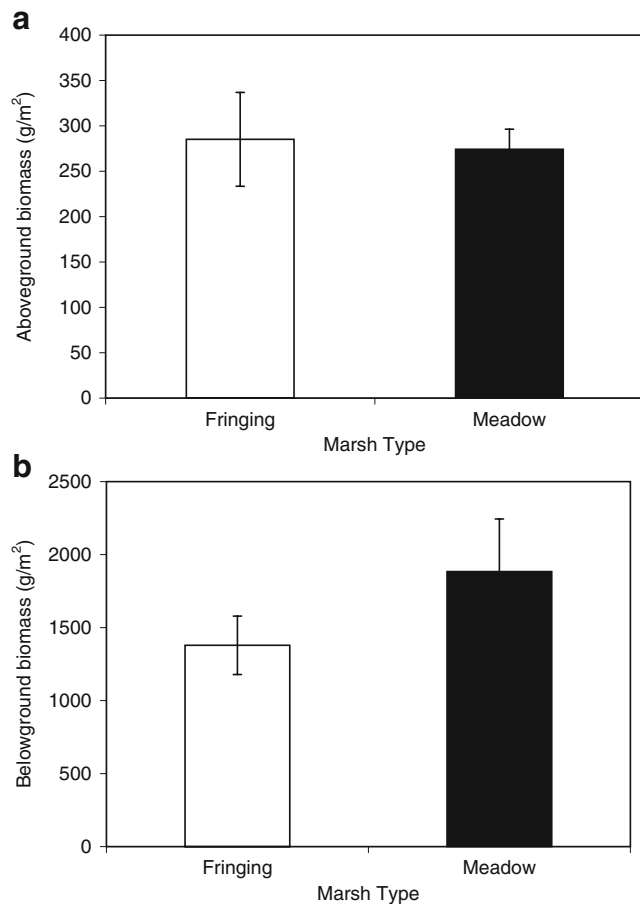


Fig. 4 **a** Aboveground and **b** belowground plant biomass of fringing and meadow salt marsh sites. Error bars are ± 1 SE from the mean. Neither aboveground ($F=0.010$, $p=0.924$) nor belowground ($F=1.999$, $p=0.195$, $1/x$ -transformed) biomass was significantly different between fringing and meadow marshes

production agree with what others have found in New England marshes (Lindthurst and Reimold 1978; Gross et al. 1991).

The positive relationship we observed between above and belowground production and surface slope ($r=0.941$ and $r=0.951$, respectively) could be attributed to the “streamside effect.” In general, marsh surfaces are more steeply sloped where they are adjacent to tidal waters, either along the edge of a creek or along the seaward edge of the marsh, and aboveground primary production is greater here (Gallagher and Kibby 1981; Burdick et al. 1989). Soils in areas exposed to tidal waters more often are typically more well-drained, and sediment oxidation rates are higher, so gas exchange between roots and the surrounding soils can take place more rapidly than in waterlogged areas (Burdick et al. 1989). Although differences in belowground biomass production in *Spartina* marshes have not been well studied, Gallagher and Kibby (1981) found that streamside plants had greater recoverable underground reserves than back-marsh plants in a *Carex lyngbyei* tidal marsh. Ellison et al.

(1986) also found that belowground production in a Massachusetts salt marsh was greater at the marsh edge than on other parts of the marsh.

Soil Organic Matter Accumulation

Our results show that the percent organic matter content of meadow marsh soils is more than three times that of fringing marsh soils (Fig. 5a). The meadow marshes we sampled had greater surface elevations than the fringing marshes (Fig. 3b), and there was a positive correlation between elevation and soil organic matter content (Fig. 5b). Schmitt et al. (1998) also found an increase in the amount of organic matter deposited in the sediment and on the marsh surface with increasing elevation in a Massachusetts salt marsh.

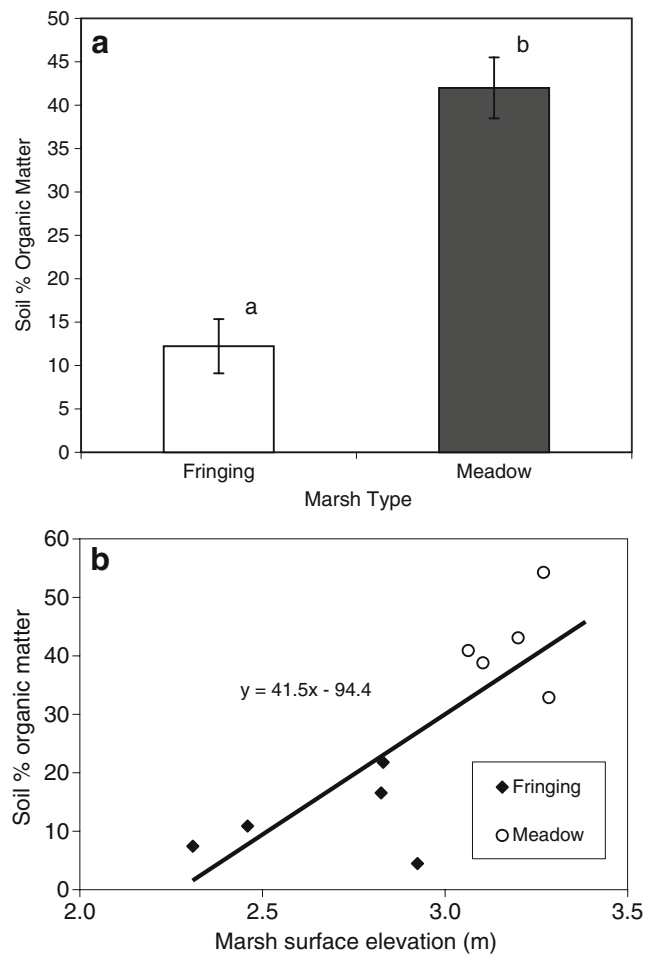


Fig. 5 **a** Percent organic matter content of fringing and meadow salt marsh soils. Error bars are ± 1 SE from the mean. Means are significantly different ($F=0.010$, $p=0.020$; elevation covariate $F=28.540$, $p=0.001$). **b** Relationship between marsh surface elevation and soil percent organic matter content for five fringing and five meadow salt marsh sites ($r=0.801$, $p<0.05$). Elevation units are meters above 0-m tide

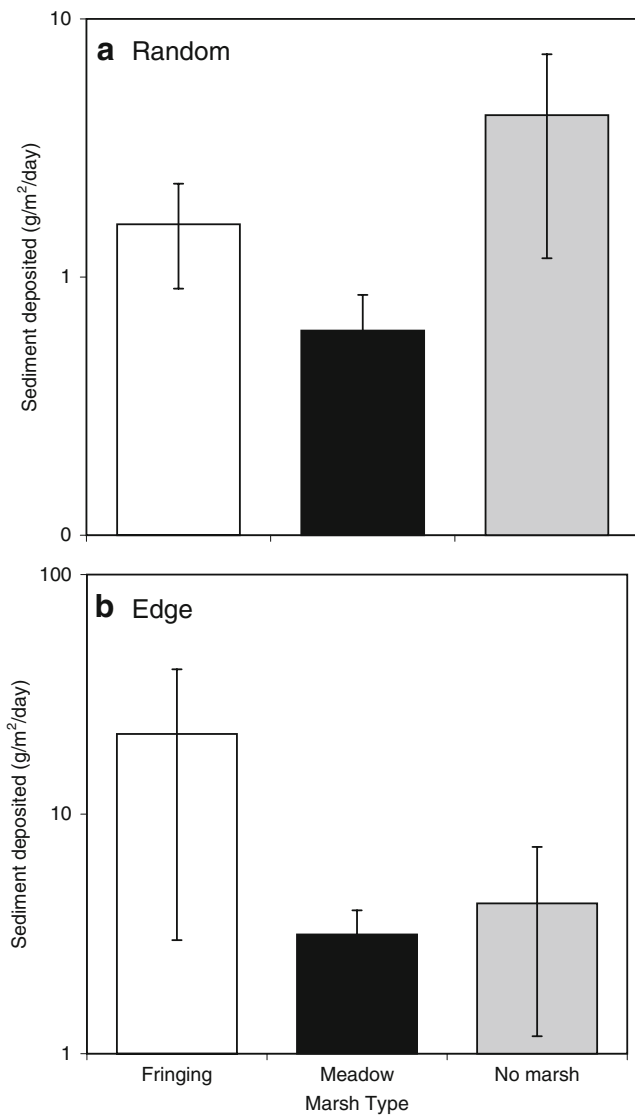


Fig. 6 Amount of sediment deposited on meadow marshes, fringing marshes, and areas where no marsh was present. Error bars are ± 1 SE from the mean. **a** Randomly distributed traps ($F=1.077$, $p=0.374$, log-transformed data; elevation covariate $F=22.385$, $p=0.0006$) and **b** traps placed 1 m from the water's edge ($F=2.591$, $p=0.120$, log-transformed data; elevation covariate $F=5.857$, $p=0.034$)

If salt marshes are to keep pace with rising sea level, they must be able to accrete at a rate equal to or greater than that of sea-level rise (Donnelly and Bertness 2001). Vertical accretion relies on two sources of sediment; one from waters that flood the marsh surface and the other from above and belowground plant biomass which does not completely decompose, contributing organic material to marsh soils. The buildup of organic matter in marsh soils appears to be most important in the high-marsh zone. In a study of five Rhode Island salt marshes, Bricker-Urso et al. (1989) found that the contribution of organic matter to accretion on the high marsh was more than twice that of inorganic sediments, but in the low marsh the contribution

of inorganic and organic sediments was equal. In addition, Ellison et al. (1986) found that the decomposition rate of live roots and rhizomes was slower in the high-marsh zone than at the marsh edge. Lower decomposition rates in interior poorly drained high-marsh soils may result in organic matter accumulation. The distance that sample points are from the marsh edge has also been observed to correlate with soil percent organic matter content. The percent organic matter in sediments of two Virginia salt marshes was lowest at the water's edge and increased along a 30-m transect into their interiors (Kastler and Wiberg 1996). In this study, we also found that the soil organic matter content correlated with the distance the sample points were from the edge of the marsh ($r=0.704$, $p<0.05$). Our results indicate that meadow marshes along the

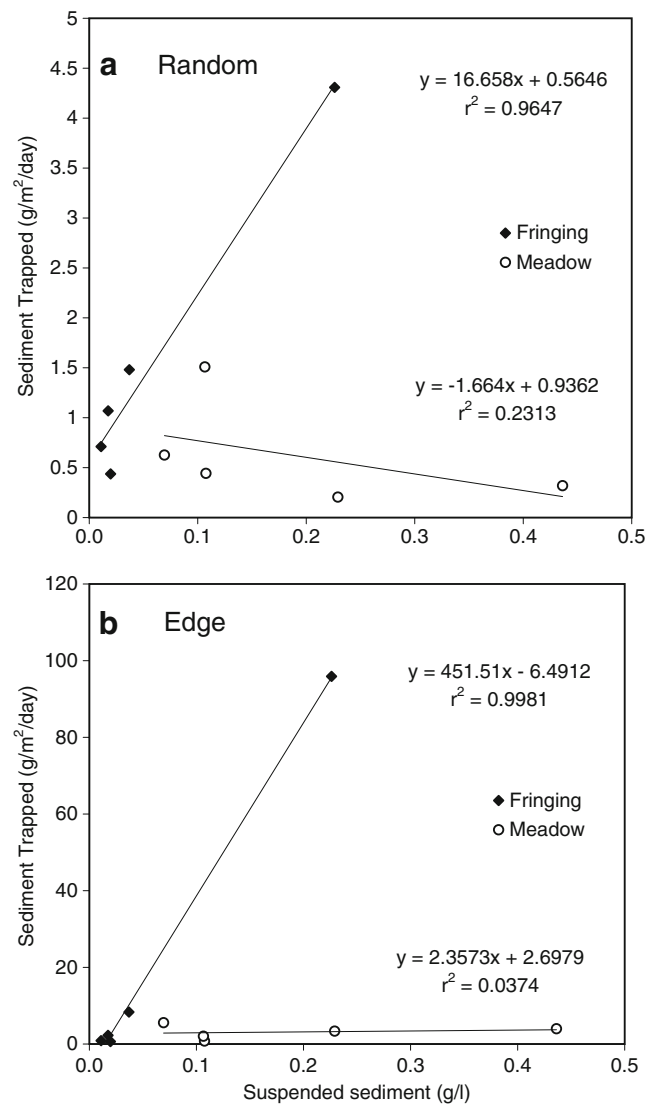


Fig. 7 Relationship between the suspended sediment concentration of tidal waters coming onto marsh sites and sediment deposition on (a) randomly distributed traps and (b) traps placed 1 m from the water's edge

Table 3 Plant community characteristics of fringing and meadow salt marsh sites

Means and standard errors are of five meadow and fringing marsh sites. Meadow marsh values in parentheses are based on 30 quadrats sampled per site; all other values are based on ten quadrats sampled per site. Values for the same characteristic followed by a different letter are significantly different from each other ($p < 0.05$)

PM *Puccinellia maritima*, *JG* *Juncus gerardii*, *SP* *Spartina patens*, *DS* *Distichlis spicata*

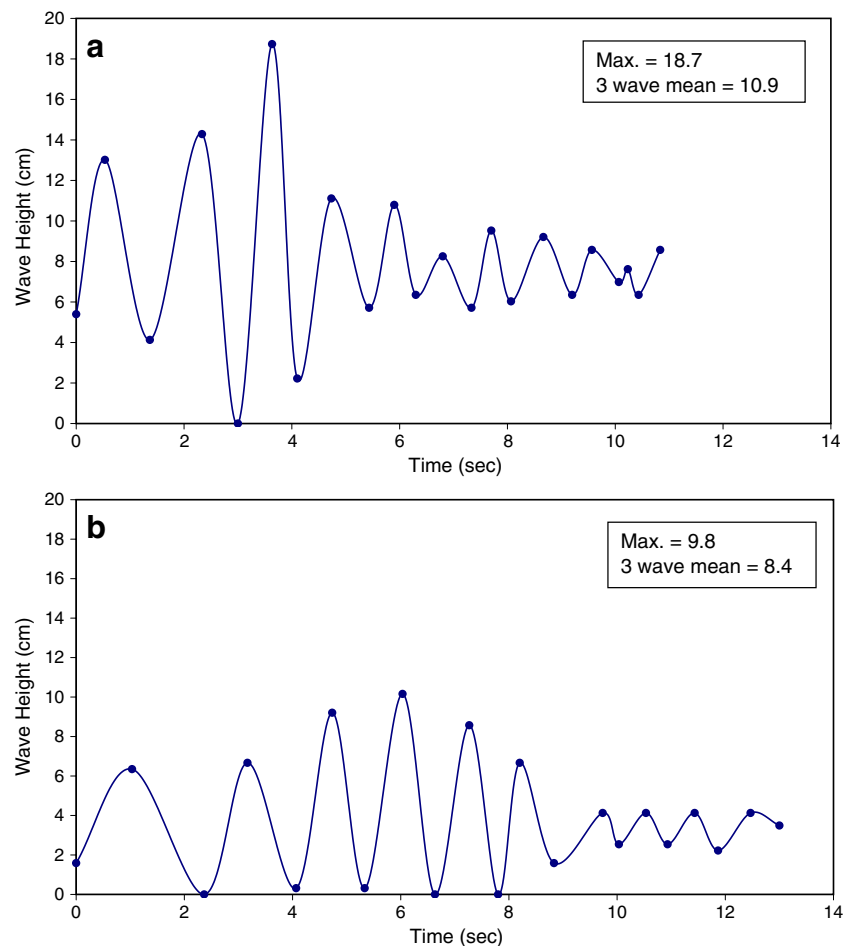
Characteristic	Fringing marsh		Meadow marsh	
	Mean	SE	Mean	SE
Species richness/site	8.8a	0.9	10.4 (15.6)b	1.0 (1.2)
Species density (#species/m ²)	2.84a	0.04	4.46b (4.84)b	0.48 (0.18)
Percent cover PM, JG, SP, DS	25.7a	11.8	52.7b (54.3)b	21.3 (4.5)
Percent cover <i>S. alterniflora</i>	34.9a	5.6	18.8 (15.6)b	7.3 (2.3)
Shannon–Weiner Index (H')	0.522	0.053	0.537	0.022
Evenness (E)	0.557	0.051	0.536	0.029

southern Maine/New Hampshire coast rely more on soil organic matter accumulation for accretion than fringing marshes do. If this is the case, then to keep pace with sea-level rise, fringing marshes must rely to a greater extent on the trapping of inorganic sediments as the mechanism of accretion.

Sediment Filtration and Trapping

Reed (1989) first developed the technique of trapping sediment on filter paper discs attached to the marsh surface. Due to the activity of green crabs in our area, we modified her design and used discs made of Mylar, which crabs do

Fig. 8 Wave profiles at MRM, a meadow marsh. Values for wave peaks and troughs were taken from videos simultaneously recording the passing waves at (a) 0 m and (b) 5 m along the transect



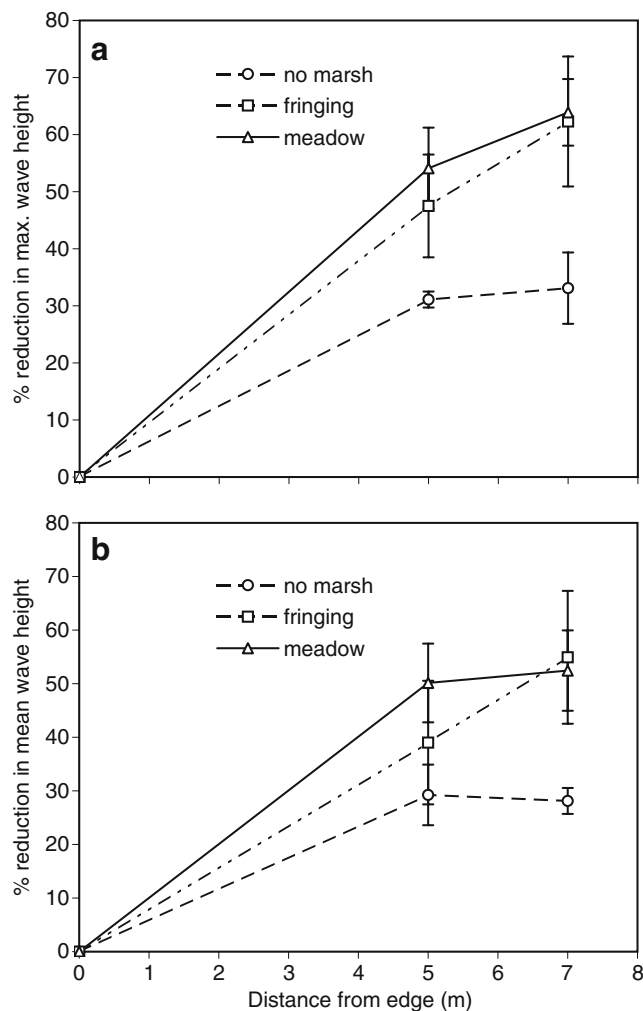


Fig. 9 Percent reduction in (a) maximum wave height and (b) “three-wave mean” height in fringing, meadow, and no-marsh areas. Error bars are ± 1 SE from the mean. At 7 m, the difference between marsh and “no-marsh” areas was statistically significant for maximum wave height ($F=5.642$, $p=0.042$, log-transformed data) but not for “three-wave mean” height ($F=4.90$, $p=0.055$, log-transformed data)

not find so appetizing. In one study of sediment deposition on Louisiana tidal marshes, Reed (1989) found rates of $2.9 \text{ g m}^{-2} \text{ day}^{-1}$ (excluding winter storm events, when sedimentation rates were much higher). We obtained similar values for sediment deposition, with marsh site means ranging from 0.44 to $4.31 \text{ g m}^{-2} \text{ day}^{-1}$ for traps randomly distributed on fringing marshes and 0.20 – $1.51 \text{ g m}^{-2} \text{ day}^{-1}$ for traps randomly distributed on meadow marshes.

We observed that sediment deposition rates decreased with increasing elevation ($r=-0.732$, $p<0.05$), probably because tidal waters cover marsh areas at higher elevations less frequently and for a shorter period of time. Negative correlations between elevation and sediment deposition have also been observed in Massachusetts (Schmitt et al. 1998) and North Carolina (Leonard 1997) salt marshes.

Intertidal areas where no marsh vegetation was present (designated as “no-marsh” areas) showed a greater rate of sediment deposition (0.62 – $16.44 \text{ g m}^{-2} \text{ day}^{-1}$) when compared to fringing marshes or meadow marshes, but these differences were not significant (Fig. 6a). Local resuspension of surface sediment on “no-marsh” sites may have contributed to greater deposition rates. We had expected to see reduced rates of sediment deposition on “no-marsh” areas, as the presence and density of marsh vegetation has been observed to correlate positively with sediment trapping (Gleason et al. 1979).

We also expected greater sediment deposition per unit area on fringing marshes than on meadow marshes because, considering the length of marsh bordering tidal waters, fringing marshes have a greater edge to area ratio than meadow marshes, so a finite sediment supply would appear as more sediment deposited per unit area on fringing marshes. We did observe higher rates of deposition on fringing marshes than on meadow marshes, but this difference was not significant (Fig. 6a), likely due to the high variability in deposition rates between sites within each site type. To eliminate any effect of the greater edge to area ratio of fringing marshes, we placed traps at fringing and meadow marsh sites just 1 m from the water’s edge. Again, the rates of sediment deposition were greater on fringing marshes, but this difference was not significant (Fig. 6b).

Our results suggest that fringing marshes trap greater amounts of sediment per unit area than meadow marshes, although the variability between sites was too high and our sample size was too small to confirm this. With slower rates of organic matter accumulation than those occurring in meadow marshes (Fig. 5a), the trapping of inorganic sediments is an important mechanism of accretion for fringing marshes. Whether fringing marshes in this area are performing the function of sediment filtration and trapping at levels sufficient to ensure that their rates of accretion will keep pace with sea-level rise is an important question that deserves further investigation.

Maintenance of Plant Diversity

Fringing salt marshes in New England are often thought to have very low plant diversity and to be comprised primarily of *S. alterniflora* (Cook et al. 1993; Bryan et al. 1997). In contrast to this, we found that fringing salt marshes often have very developed high-marsh communities. All of the fringing marshes we studied contained *S. patens*, a typical high-marsh plant, and, at two sites, *S. patens* was more abundant than *S. alterniflora*. So although the proportion of high marsh to low marsh in the fringing marshes we studied was less (0.7:1) than in meadow marshes (3.4:1), high-marsh species are an important component of fringing marsh plant communities.

Our results confirmed that meadow marshes are more species rich than fringing marshes in this part of New England (Table 3). This is likely due to the “area effect” (the number of species sampled increases with increasing sample size (Magurran 1988)); species richness was correlated with marsh area ($r=0.818$, $p<0.05$). Species density (number of species present per square meter) was also greater in meadow marshes than in fringing marshes and correlated with marsh area ($r=0.676$, $p<0.05$).

The low-marsh zone in New England salt marshes is typically dominated by *S. alterniflora*, and the sites we studied fit this pattern. However, the high-marsh zone of the majority of the meadow marshes in our study did not fit the pattern commonly observed in other New England marshes, where there are distinct bands of *S. patens* and *J. gerardii* (Miller and Egler 1950; Niering and Warren 1980). Instead, the high marsh often contained large areas of forbs (broad-leaved plants), in a mosaic of patches of *S. patens*, *J. gerardii*, and other dominant high-marsh grasses. Ewenschuck and Bertness (2004) also noted the occurrence of forb pannes in a Wells, Maine marsh (one of our study sites) and attributed the occurrence of these forb patches to the waterlogged anoxic soils found in northern New England salt marshes. Jacobson and Jacobson (1989) found mosaic patterns of vegetation in a number of the Maine salt marshes they sampled, which they hypothesized was due to micro-relief in high-marsh areas.

Although meadow marshes have greater species richness and density, their plant communities are comparable to those of fringing marshes in terms of two other measures of plant diversity, the Shannon–Weiner index (H') and evenness index (E ; Table 3). The evenness index we employed 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 are equal. Our results show that the relative abundances of species were similar in the fringing and meadow marsh sites we sampled. These results are based on ten quadrats sampled in both fringing and meadow marshes, as equal sample sizes must be used when calculating H' and E .

Dissipation of Physical Forces of Waves

Previous studies have shown that salt marshes reduce the height and energy of incoming waves, helping to protect the adjacent upland from erosion (Knutson et al. 1982; Moeller et al. 1996). In addition, salt marshes reduce wave velocity, resulting in increased sediment deposition on the marsh surface and decreased sediment erosion (Leonard and Luther 1995). We were interested in knowing if marsh type (fringing or meadow) or other characteristics (vegetation,

slope) affected a marsh's ability to reduce the height (energy) of incoming waves.

Marsh type does not affect a site's ability to reduce the height of incoming waves, with fringing and meadow marshes both causing waves to lose energy as they traveled 7 m across the marsh surface (Fig. 9). Maximum wave height was reduced 62% in fringing marshes and 64% in meadow marshes after traveling 7 m across the marsh surface. These values are similar to those obtained by Knutson et al. (1982), who found wave heights reduced by 57% 5 m into a *S. alterniflora* marsh, and 65% at 10 m. Leonard and Luther (1995) found a 65% reduction in the turbulent energy of water coming onto the marsh after it had traveled just 3 m in from the marsh edge.

Areas where no marsh was present were much less effective at reducing the height of maximum waves (33% over 7 m), as expected. In the study of a *S. alterniflora* marsh in England by Moeller et al. (1996), they found that low-marsh areas absorbed two to three times as much wave energy as adjacent sand flats. Our results demonstrate that, for waves up to 27 cm in height (typical of boat- or wind-generated waves), even narrow fringing marshes are capable of reducing wave energy by almost two thirds, helping to protect adjacent shorelines from the erosive forces of waves.

Although there have been some studies of fringing marsh ecology (e.g., Davis et al. 2004; Bozeck and Burdick 2005), few studies have considered fringing salt marshes as unique habitats, distinct from larger, meadow salt marshes. In many New England estuaries, fringing salt marshes are the dominant marsh type, and yet regional efforts aimed at marsh conservation and restoration still focus on larger meadow marshes (Konisky et al. 2006; Taylor 2008). With an improved understanding of the ecological functions of fringing marshes and of their value to coastal communities, we can do a better job of protecting and restoring these important resources.

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References

- Bozeck, C.M., and D.M. Burdick. 2005. Impacts of seawalls on salt marsh plant communities in the Great Bay Estuary, New Hampshire USA. *Wetlands Ecology and Management* 13(5): 553–568. doi:10.1007/s11273-004-5543-z.

- Bricker-Urso, S., S.W. Nixon, J.K. Cochran, D.J. Hirschberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. *Estuaries* 12: 300–317. doi:10.2307/1351908.
- Bryan, R.R., M. Dionne, R.A. Cook, J. Jones, and A. Goodspeed. 1997. *Maine citizens guide to evaluating, restoring, and managing tidal marshes*. Falmouth: Maine Audubon Society.
- Burdick, D.M., I.A. Mendelssohn, and K.L. McKee. 1989. Live standing crop and metabolism of the marsh grass *Spartina patens* as related to edaphic factors in a brackish, mixed marsh community in Louisiana. *Estuaries* 12(3): 195–204. doi:10.2307/1351824.
- Cook, R.A., A.J. Lindley Stone, and A.P. Amman. 1993. *Method for the evaluation and inventory of vegetated tidal marshes in New Hampshire*. Concord: Audubon Society of New Hampshire.
- Craft, C.B., E.D. Seneca, and S.W. Broome. 1991. Loss on ignition and Kjeldahl digestion for estimating organic carbon and total nitrogen in estuarine marsh soils: Calibration with dry combustion. *Estuaries* 14: 175–179. doi:10.2307/1351691.
- Davis, J., B. Nowicki, and C. Wigand. 2004. Denitrification of fringing salt marshes of Narragansett Bay, Rhode Island, USA. *Wetlands* 24(4): 870–878. doi:10.1672/0277-5212(2004)024[0870:DIFSMO]2.0.CO;2.
- Denny, M.W. 1988. *Biology and the mechanics of the wave-swept environment*. Princeton: Princeton University Press.
- Donnelly, J.P., and M.D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. *Proceedings of the National Academy of Sciences* 98(25): 14218–14223. doi:10.1073/pnas.251209298.
- Ellison, A.M., M.D. Bertness, and T. Miller. 1986. Seasonal patterns in the belowground biomass of *Spartina alterniflora* (Gramineae) across a tidal gradient. *American Journal of Botany* 73(11): 1548–1554. doi:10.2307/2443921.
- Ewenchuck, P.J., and M.D. Bertness. 2004. Structure and organization of a northern New England salt marsh plant community. *Journal of Ecology* 92: 72–85. doi:10.1111/j.1365-2745.2004.00838.x.
- Gallagher, J.L., and H.V. Kibby. 1981. The streamside effect in a *Carex lyngbyei* estuarine marsh: The possible role of recoverable underground reserves. *Estuarine, Coastal and Shelf Science* 12: 451–460. doi:10.1016/S0302-3524(81)80004-7.
- Gleason, M.L., D. Elmer, and N.C. Pien. 1979. Effects of stem density upon sediment retention by salt marsh cord grass, *Spartina alterniflora* Loisel. *Estuaries* 2: 271–273. doi:10.2307/1351574.
- Gross, M.F., M.A. Hardisky, P.L. Wolf, and V. Klemas. 1991. Relationship between aboveground and belowground biomass of *Spartina alterniflora* (smooth cordgrass). *Estuaries* 14: 180–191. doi:10.2307/1351692.
- Jacobson, H.A., and G.L.J. Jacobson. 1989. Variability of vegetation in tidal marshes of Maine, U.S.A. *Canadian Journal of Botany* 67: 230–238. doi:10.1139/b89-032.
- Kastler, J.A., and P.L. Wiberg. 1996. Sedimentation and boundary changes of Virginia salt marshes. *Estuarine, Coastal, and Shelf Science* 42: 683–700. doi:10.1006/ecss.1996.0044.
- Knutson, P.L., R.A. Brochu, W.N. Seelig, and M. Inskeep. 1982. Wave dampening in *Spartina alterniflora* marshes. *Wetlands* 2: 87–104.
- Konisky, R.A., D.M. Burdick, M. Dionne, and H.A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. *Restoration Ecology* 14(4): 516–525. doi:10.1111/j.1526-100X.2006.00163.x.
- Leonard, L. 1997. Controls of sediment transport and deposition in an incised mainland marsh basin, southeastern North Carolina. *Wetlands* 17(2): 263–274.
- Leonard, L.A., and M.E. Luther. 1995. Flow hydrodynamics in tidal marsh canopies. *Limnology and Oceanography* 40: 1474–1484.
- Lindthrust, R.A., and R.J. Reimold. 1978. An evaluation of methods for estimating the net aerial primary productivity of estuarine angiosperms. *Journal of Applied Ecology* 15: 919–931. doi:10.2307/2402787.
- Lyons, J., J. Ahern, J. McClelland, and I. Valiela. 1995. Macrophyte abundances in Waquoit Bay estuaries subject to different nutrient loads and the potential role of fringing salt marsh in groundwater nitrogen interception. *Biological Bulletin* 189: 255–256.
- Magurran, A.C. 1988. *Ecological diversity and its measurement*. Princeton: Princeton University Press.
- Marinucci, A.C. 1982. Trophic importance of *Spartina alterniflora* production and decomposition to the marsh–estuarine ecosystem. *Biological Conservation* 22: 35–58. doi:10.1016/0006-3207(82)90096-9.
- Miller, W.B., and F.E. Egler. 1950. Vegetation of the Wequetequoick–Pawcatuck tidal marshes, Connecticut. *Ecological Monographs* 20: 143–172. doi:10.2307/1943548.
- Moeller, I., T. Spencer, and J.R. French. 1996. Wind wave attenuation over salt marsh surfaces: Preliminary results from Norfolk, England. *Journal of Coastal Research* 12: 1009–1016.
- Morgan, P.A., and F.T. Short. 2002. Using functional trajectories to model constructed salt marsh development in the Great Bay Estuary, ME/NH. *Restoration Ecology* 10(3): 461–473. doi:10.1046/j.1526-100X.2002.01037.x.
- Niering, W.A., and R.S. Warren. 1980. Vegetation patterns and processes in New England salt marshes. *Bioscience* 30: 300–306. doi:10.2307/1307853.
- Nixon, S.W., and C.A. Oviatt. 1973. Analysis of local variation in the standing crop of *Spartina alterniflora*. *Botanica Marina* 16: 103–109.
- Reed, D.J. 1989. Patterns of sediment deposition in subsiding coastal salt marshes, Terrebonne Bay, Louisiana: The role of winter storms. *Estuaries* 12: 222–227. doi:10.2307/1351901.
- Roman, C.T., N. Jaworski, F.T. Short, S. Findlay, and R.S. Warren. 2000. Estuaries of the northeastern United States: Habitat and land use signatures. *Estuaries* 23(6): 743–764. doi:10.2307/1352997.
- Schmitt, C., N. Weston, and C. Hopkinson. 1998. Preliminary evaluation of sedimentation rates and species distribution in Plum Island Estuary, Massachusetts. *The Biological Bulletin* 195: 232–233. doi:10.2307/1542855.
- Short, F.T., D.M. Burdick, C.A. Short, R.C. Davis, and P.A. Morgan. 2000. Developing success criteria for restored eelgrass, salt marsh and mud flat habitats. *Ecological Engineering* 15(3): 239–252. doi:10.1016/S0925-8574(00)00079-3.
- Teal, J.M. 1986. The ecology of regularly flooded salt marshes of New England: A community profile. US Fish and Wildlife Service, Biological Report No. 85 (7.4).
- Taylor, P.H. 2008. Salt marshes in the Gulf of Maine: Human impacts, habitat restoration and long-term change analysis. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org. IV + 42 pp.
- Tobias, C.R., I.C. Anderson, E.A. Canuel, and S.A. Macko. 2001. Nitrogen cycling through a fringing marsh–aquifer ecotone. *Marine Ecology Progress Series* 210: 25–39. doi:10.3354/meps210025.