Fall 2000

Conservation and ecology of fringing salt marshes along the southern Maine/New Hampshire coast

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CONSERVATION AND ECOLOGY OF FRINGING SALT MARSHES ALONG THE SOUTHERN MAINE/NEW HAMPSHIRE COAST

BY

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DISSERTATION

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Doctor of Philosophy
in

Natural Resources

September, 2000

UMI Number: 9983717

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DEDICATION

This dissertation is dedicated to my family, and especially to Todd.

ACKNOWLEDGEMENTS

I thank my thesis advisor, Dr. Frederick T. Short, for his guidance and support throughout my time as a Ph.D. student, and for his willingness to take on a student who insisted on studying salt marshes! I have learned an enormous amount about the conservation and ecology of estuaries from Fred. Thanks also to my thesis committee, Dr. Breck Bowden, Dr. David Burdick, Dr. Tom Lee and Dr. Frank Richardson for their advice, critique and support over the past five years. Thanks to Breck for two great wetlands classes, and for inspiring me to want to teach a wetlands course myself some day. A special thanks to Dave, who gave me my first lesson in salt marsh field work. Dave's knowledge of salt marshes and statistics were invaluable to me, and his energy and enthusiasm for salt marsh research were contagious. Thanks to Tom for patiently teaching me so much about plant community diversity sampling and data analysis. And thanks to Frank for teaching me about the historical perspective of salt marshes.

I would like to thank Dr. Michele Dionne for facilitating my work at the Wells National Estuarine Research Reserve and for her advice during my NERR fellowship. Dr. Ryan Davis was a great help during my early years as a Ph.D. student, and I thank him for many discussions about estuarine research and life in general. Thanks also to the graduate students and post-docs at the Jackson Estuarine Laboratory who provided support and friendship over the years: Heidi Hoven, Alison Bowden, Blaine Kopp, Kalle Matso and Jeff Gaeckle. In addition, many undergraduate students at UNH and at the University of New England assisted me over the years with field work, lab work and data entry. Thank you also to Cathy Short for editing all of this, and for helping me become a better writer.

I could not have completed this degree without the support and friendship of my colleagues at the University of New England, who always had warm words of encouragement for me. A special thanks to Dr. Jacque Carter and to Dr. Eleanor Saboski, who helped me find the time and the confidence to complete this degree.

And finally, I would like to acknowledge Dr. William Niering, who I was fortunate enough to have as a teacher when I was thinking about going back to graduate school. Dr. Niering introduced me to wetland restoration, and made me realize that this was the field of study for me.

Funding for this research was provided by the NOAA National Estuarine Research Reserve Program, the New Hampshire Port Authority, the University of New Hampshire and the University of New England.

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ABSTRACT

CONSERVATION AND ECOLOGY OF FRINGING SALT MARSHES ALONG THE SOUTHERN MAINE/NEW HAMPSHIRE COAST

by

Pamela A. Morgan

University of New Hampshire, September 2000

The small, fringing salt marshes that line the edges of estuaries in southern Maine and New Hampshire were the focus of this research. Although larger meadow marshes in New England have been studied extensively, little is known about the ecology of fringing marshes. Not only are fringing marshes much more numerous than meadow marshes in northern New England, they are often restored or created as mitigation for marsh impacts. Five ecological functions (primary production, soil organic matter accumulation, sediment trapping and binding, wave dampening and maintenance of plant diversity) were compared in meadow marsh and fringing marsh sites, and sometimes in areas where no marsh was present. Also explored were the relationships between these functions and several physical characteristics, including soil salinity, percent surface slope, elevation and size. Fringing marsh and meadow marsh sites differed significantly in terms of their physical characteristics, but functional indicator values were similar, with the exception of plant species richness and soil organic matter content.

A field experiment tested whether marsh surface slope or north-south orientation affects the growth of newly planted cordgrass (*Spartina alterniflora*) in fringing marshes. These experiments were not able to show that orientation or slope had an effect on plant growth.

Comparisons were also made between six constructed fringing marshes and a set of selected reference sites (matched to constructed marshes using principal components analysis) in the Great Bay Estuary. Four ecological functions (primary production, soil organic matter accumulation, sediment trapping and binding, and maintenance of plant diversity) were studied. Mean values for constructed site (n=6) and reference site (n=11) functions were significantly different. Because the age of the constructed sites ranged from 1- 14 years, patterns of functional development could be examined. Using constructed marsh age as the independent variable and functional indicator values as dependent variables, non-linear regression analyses produced several ecologically meaningful trajectories (r^2>0.9). These models illustrate that although indicators of some functions (primary production, sediment deposition, and plant species richness) should reach natural site values in less than ten years, soil organic matter content will take more than fifteen years to develop.

CHAPTER I

INTRODUCTION

Background

New England's salt marshes are unique habitats that buffer the edge of land and sea. At first glance they appear as no more than dense stands of green grass, but upon closer inspection their diversity is revealed. Not only do salt marshes contain a variety of plants that form complex mosaics on their surfaces; they are also home to a great number of microbes and invertebrates, organisms that are essential to the marsh food web. The surface of a salt marsh may also contain pools and pannes where birds such as the great blue heron and snowy egret feed on small fish like silversides and mummichogs. And because the tide rises and falls twice a day, sometimes covering the entire marsh surface and sometimes just flooding its edges, a salt marsh never looks exactly the same. Fortunately, people have come to appreciate the value of these unique communities, and over the years much has been learned about their role in the estuary. And yet despite our increased knowledge and appreciation of salt marshes, many are still being negatively impacted by human activities.

Salt marshes are commonly found in the protected areas along the edges of rivers and bays or behind barrier beaches (Nixon 1982). Protection from the energy of large waves is necessary because marshes depend on inorganic sediment deposition to help them keep pace with rising sea level (Redfield 1972). The process of marsh accretion is facilitated by stands of salt marsh grasses that slow the waters passing over the surface of a marsh, allowing much of the sediment suspended by these waters to be deposited. Marsh vegetation also contributes partially decomposed plant material to the building of marsh soils. Chapman (1960) explained that the soils of New England marshes (found from Maine to New Jersey) are different from those of marshes located farther south because they are comprised primarily of peat, an organic material made of plant remains. The hard-rock uplands in New England provide little erosional material to the rivers and streams flowing into salt marshes. In contrast, rivers and streams southward from New Jersey contain an abundant supply of silt, which contributes to marsh accretion and is the predominant component of southern salt marsh soils.

The accretion of organic and inorganic sediment is essential to the persistence of salt marshes because they must maintain rather precise elevations relative to sea level to support their unique plant communities. Large-scale patterns of salt marsh vegetation occur largely in response to tidal flooding, the extent of which is directly related to marsh surface elevation. Areas of the marsh that are flooded twice a day by the tides are dominated by cordgrass (*Spartina alterniflora)*, a plant that can withstand high soil salinity and waterlogged soils, and areas that flood only during monthly spring tides are dominated by stands of salt meadow hay (*Spartina patens*) and black grass (*Juncus gerardii*). Miller and Egler (1950) were the first to thoroughly describe a "theoretical upland to bay sequence" of plants after studying the vegetation of several Connecticut marshes. They observed the following sequence of vegetation belts from upland to salt water: (1) the *Panicum virgatum* Upper Border, (2) the *Juncus* Upper Slope, (3) the *Spartina patens* Lower Slope and (4) the *Spartina alterniflora* Lower Border. However, they acknowledged that because of pannes, pools, erosion spots, levees, ditches and other features, the actual plant communities often looked more like a complicated mosaic. Thirty years later, Niering and Warren (1980) further investigated the structure of New England's salt marsh plant communities by surveying more than 100 marsh systems in Long Island Sound. They discovered a complexity of vegetation patterns on the high marsh that they attributed to differences in environmental factors, including salinity, hydroperiod and soil oxygen availability. They also observed that the basic belting pattern at the site originally studied by Miller and Egler no longer existed, evidence that marsh vegetation patterns are not static over time. Their results underscored the statement made by Miller and Egler in 1950: "The present mosaic may be thought of as a momentary expression, different in the past and destined to be different in the future and yet as typical as would be a photograph of moving clouds."

On the geologic time scale, New England's salt marshes are relatively young. The oldest marshes are estimated to be 4,000 years old, having formed well after the last glaciers retreated from the area (Redfield 1972). Although deglaciation of the Maine coast is estimated to have occurred 13,800-13,200 years ago, conditions were not right for the formation of extensive salt marshes until 4,000 years ago, when the rise in sea level slowed enough to allow for the development of barrier beaches. These barriers then provided the protected environment necessary for the establishment of large salt marshes (Kelly 1992). However many salt marshes, including Maine's smaller marshes, are much younger than this, having formed, eroded and reformed in a cyclical pattern in response to sediment inputs from adjacent bluffs and the erosive forces of waves (Kelly et al. 1988). As sea level has risen and fringing marshes have eroded along their seaward edges, they have colonized adjacent upland (given an adequate supply of sediment), thereby persisting over time (Kelly 1992).

Salt marshes are considered to be very productive ecosystems. Nixon (1982) summarized studies of aboveground production in New England salt marshes and reported values ranging from 250-705 g dry wt/m^2/yr where *S. alterniflora* was the dominant species, and from 300-2740 g dry wt/m^2/yr where *S. patens*, *J. gerardii* and other high marsh species were dominant. Algae (macroalgae and microalgae) growing on the marsh surface or on marsh plants also contribute to salt marsh primary production, but the contribution of algal production to total marsh production is not well understood (Teal 1986). Salt marsh primary production feeds detrital food webs, and to a more limited extent, grazing food webs within the marsh system. Some of the energy trapped by salt marshes may also contribute to estuarine and offshore food webs after it has been exported from the marsh (Day et al. 1989). The high primary productivity of salt marshes is an important function of New England salt marshes.

Salt marshes perform a number of ecological functions, and each of them can be associated with one or more values (Short et. al 2000). Whereas the functions of salt marshes are ecological processes that occur over time and do not depend on societal perceptions, the values associated with these functions are important to people (Brinson and Rheinhardt 1996, U.S. Army Corps of Engineers 1995). For example, as stated above, the function of marsh primary production is linked to the value of supporting fish and wildlife through estuarine and offshore food webs. Other examples of salt marsh values include their ability to improve water quality, counter the effects of sea level rise, and protect upland areas from the erosive forces of waves. Measurable functions that correspond with these values include nutrient and contaminant filtration, sediment filtration and trapping, and wave and current energy dampening (Short et al. 2000).

Almost all that we know today about the ecological processes of Atlantic coast salt marshes is based on studies conducted in large meadow marshes located south of Maine and New Hampshire. The term meadow marsh refers to salt marshes that are large in size and that have formed behind barrier beaches or in the protected areas along the edges of rivers and bays (Cook et al. 1993). Meadow marshes can be further separated into two geomorphological types, back-barrier marshes, associated with barrier beaches and having direct access to the ocean, and finger marshes, associated with tidal bays or rivers (Bryan et al. 1997). Fringing marshes are different from meadow marshes because they are narrow in width and are generally thought to be comprised primarily of *S. alterniflora* (Cook et al. 1993; Bryan et al. 1997). In addition, their peat soils are much shallower than those of larger meadow marshes, and they are much less likely to be preserved in the geological record than meadow marshes. Peat depths in Maine and New Hampshire's meadow marshes are typically 3-5 meters (Breeding et al. 1974; Jacobson et al. 1987; Kelly et al. 1988). In contrast, peat depths in fringing marshes located in downeast Maine have been observed to contain less than 0.5 m of peat (Jacobson et al. 1987).

Like their larger counterparts, fringing marshes form along the protected shores of rivers and bays, but they remain narrow bands along the shoreline due to a combination of factors, including the nature of the wave and current energies affecting them and the sediment loads in the waters flooding their surfaces (Kelly et al 1988). Very few studies have focused on the smaller fringing marshes that become more common as one moves northward along the coast of Maine (Jacobson and Jacobson 1989).

The actual number or acreage of small, fringing marshes along the New England coast has not been documented, with the exception of a study conducted in the state of Maine. Jacobson et al. (1987) delineated the salt marshes in Maine greater than 150 m^2 using planimetry and discovered that more than 40% of the total marsh area in the state was comprised of marshes of mean size of 0.026 km^2 (6.4 acres) and smaller. Because earlier surveys had not counted the many small marshes scattered along Maine's convoluted coastline, the number of salt marsh acres had been underestimated by a factor of thirteen. These results led the authors to point out the significant cumulative contribution that Maine's small salt marshes must make in terms of primary productivity to the Gulf of Maine (Jacobson et al. 1987).

To help clarify the role of fringing marshes in the estuaries of Maine and New Hampshire, I studied several of their ecological functions, including primary production. Other functions studied were the maintenance of plant biodiversity, soil organic matter accumulation, sediment trapping and binding, and dissipation of the physical forces of waves. Adding to our limited understanding of fringing marsh functions was one objective of this dissertation. This increased knowledge should allow resource managers to make better decisions concerning the future of fringing marshes, and should help coastal communities to better appreciate the value of these marshes. Five fringing salt marshes and five larger, meadow marshes were selected for study in southern Maine and New Hampshire (Figure 1), and a number of their ecological functions were compared.

Because they are located along the edges of rivers and bays, where human development pressures are great, fringing salt marshes are particularly susceptible to anthropogenic impacts. They are often abutted by residential and commercial development, and so can be impacted by contaminated runoff from adjacent developed areas (Bryan et al. 1997). Vegetation on the surface of fringing marshes can be killed when debris is dumped on their landward edges, or when docks and boat ramps are built to provide access to open water for small boats. In addition, I have observed fishermen to inadvertently trample vegetation so severely that it does not recover. Fringing salt marshes are also threatened by rising sea level if structures along their upland borders block their future landward migration (Kelly 1992). Although current wetland laws protect fringing marshes, there are certain circumstances where entire marshes may be lost because of coastal development currently deemed necessary by government agencies.

Both Maine and New Hampshire have laws that protect coastal marshes. In New Hampshire, a permit is required for activities that impact tidal wetlands. If impacts to a wetland are deemed unavoidable, a permit may be granted to the applicant in accordance with the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers mitigation policy (Section 404(b)(1) Guidelines Mitigation MOA, 55 Fed. Reg. 9210 (Feb 7, 1990)). This policy states that permits may be granted only after applicants demonstrate that attempts have been made first to avoid impacts to the wetland and then to minimize any impacts (Berry and Dennison 1993). If a permit applicant can demonstrate that no practicable alternative is less damaging to the environment (cost, engineering and logistics are considered in this decision), a permit may be issued along with a requirement for mitigation (USEPA 1986).

The goal of mitigation is to replace the functions and values of the impacted site by restoring, enhancing or preserving existing wetlands, or through the creation of new

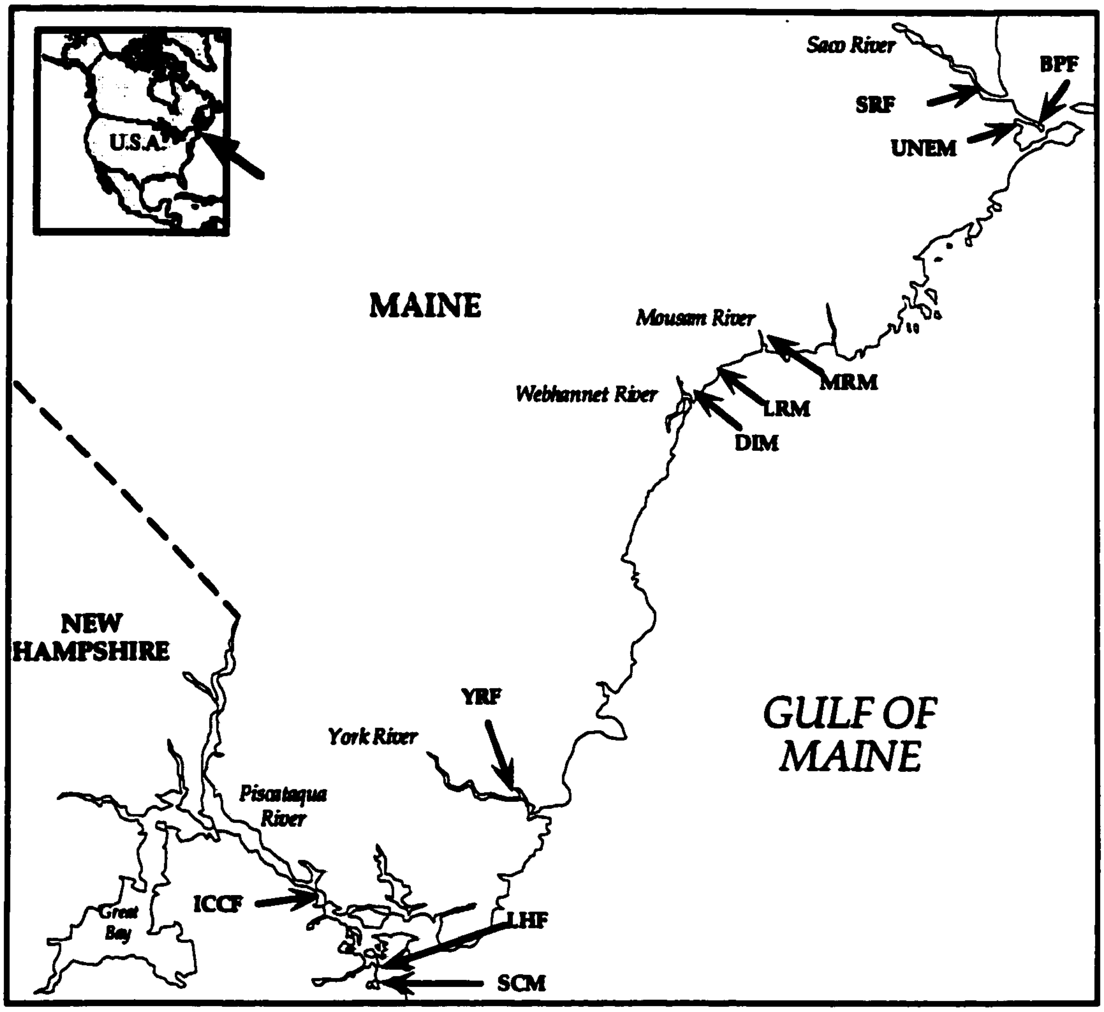


Figure 1. Locations of fringing and meadow marsh study sites. Complete site names and locations (latitude/longitude) are listed in Appendix Table 1. Sites ending in "F" are fringing marshes; sites ending in "M" are meadow marshes.

wetlands (Kruczynski 1990). Restoration can be defined as returning an altered wetland to its former natural state, or to a previous altered condition, whereas enhancement is increasing one or more functions of an existing wetland. Creation is the conversion of non-wetland habitat into a wetland through some activity of man (Lewis 1990).

Salt marsh creation and restoration have occurred since the 1970s, but many questions remain concerning whether constructed[1] sites will reach functional equivalency with natural salt marshes (Race and Christie 1982). Evaluating the functional success of created and restored salt marshes has been an active area of research among estuarine ecologists. Numerous studies have been conducted in New England (e.g. Roman et al. 1984; Shisler and Charette 1984; Sinicrope et al. 1990; Burdick et al. 1997; Short et al. 2000), but few of these have focused on salt marshes in Maine and New Hampshire, and none have specifically examined fringing marshes.

I investigated whether constructed fringing marshes along the southern Maine and New Hampshire coasts were functioning like natural fringing marshes. In addition, I investigated whether we could predict how long it might take for constructed sites to reach functional equivalency with natural salt marshes. I addressed these questions by studying six different-aged constructed salt marshes in the Great Bay Estuary (Fig. 2), and by comparing several of their functions to those of reference marshes in the Estuary.

Because the current wetland policy which allows for marsh construction as a way to compensate for the loss of wetland areas is not likely to change in the near future (Berry and Dennison 1993), scientists and resource managers need to establish a scientific basis for improving existing wetland construction methods. A variety of techniques for establishing vegetation on newly-constructed salt marshes have been attempted over the years, including seeding, planting greenhouse-grown seedlings, and transplanting field-harvested *S. alterniflora* plants (Broome et al. 1988). *S. alterniflora* is

[1] The term constructed will be used to mean either restored or created.

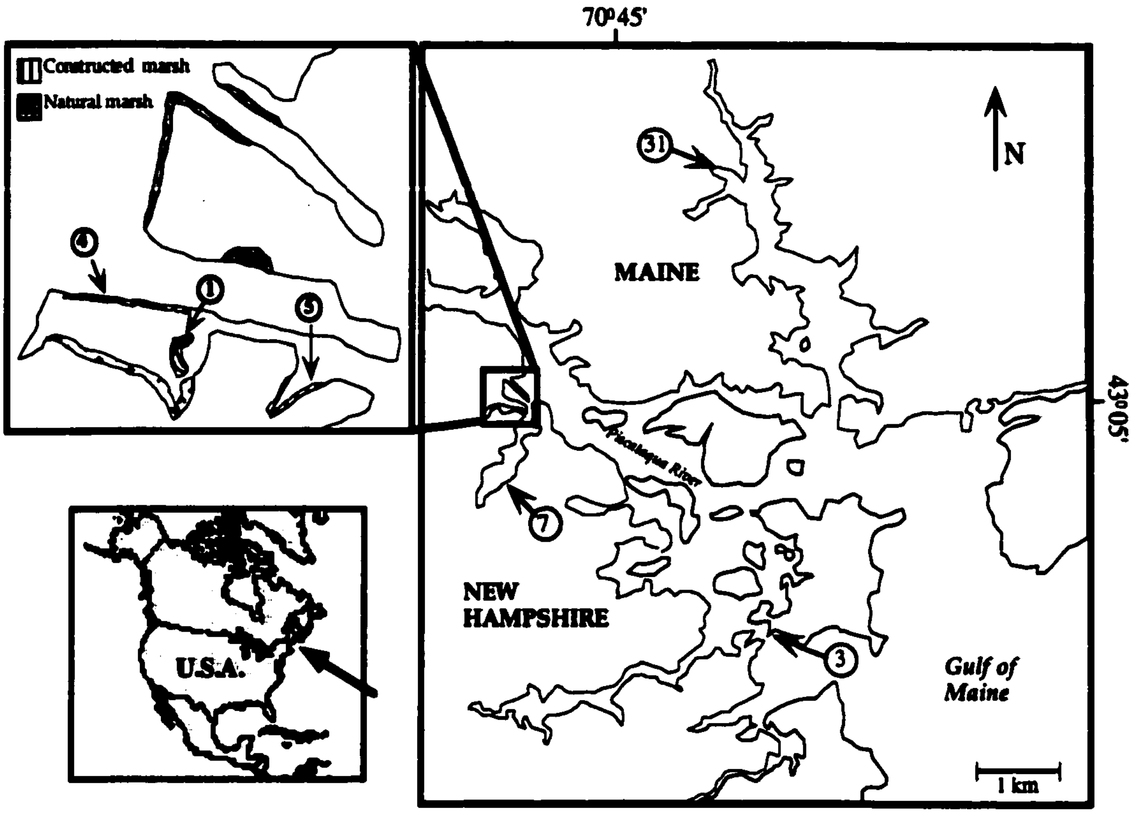


Figure 2. Location of constructed sites within the Great Bay Estuary. Sites are indicated by circled numbers.

the recommended species for planting, as sites planted with cordgrass have been more successful than those planted with high marsh species (Shisler and Charette 1984). A healthy cover of vegetation can help stabilize sediments and slow erosion, so promoting the early establishment and growth of *S. alterniflora* on newly constructed marshes can improve a site's chances for success (Shisler 1990).

My observations of the variability in growth among *S. alterniflora* plants in natural and constructed marshes in the Great Bay Estuary led me to ask if marsh surface slope might affect the growth of transplanted cordgrass. I was also interested in investigating whether the north-south orientation of constructed sites affects plant growth. I addressed these questions by conducting a field experiment to determine if surface slope and north-south orientation affect the growth of newly planted *S. alterniflora*.

Objectives

Following is a list of objectives that guided my investigation of fringing salt marsh ecology, my study of factors affecting the growth of transplanted *S. alterniflora*, and my evaluation of constructed fringing marshes in the Great Bay Estuary. Specifically, my research objectives were:

(1) To further our understanding of the role of fringing salt marshes in the estuaries of southern Maine and New Hampshire by comparing several of their ecological functions to those of larger, meadow salt marshes and to areas where no salt marsh is present. The functions assessed included primary production, maintenance of plant biodiversity, soil organic matter accumulation, sediment filtration and trapping, and dissipation of the physical forces of waves.

(2) To investigate the effect of north/south orientation and marsh surface slope on the growth of *Spartina alterniflora* transplants during a growing season.

(3) To compare several functions of constructed fringing salt marshes to those of natural fringing salt marshes in the Great Bay Estuary, and to investigate whether a constructed site's age and level of function are related in a predictable way that can be modeled using trajectories The salt marsh functions assessed included primary production, maintenance of plant biodiversity, soil organic matter accumulation, and sediment filtration and trapping.

Organization of the Thesis

Chapter II explores the role that fringing salt marshes play in the estuaries of southern Maine and New Hampshire. To address this, I compared several ecological functions (primary production, maintenance of plant biodiversity and soil organic matter accumulation) in five fringing salt marshes and five meadow marshes. In addition, I compared the functions of sediment filtration and trapping and dissipation of the physical forces of waves between fringing marshes, meadow marshes, and areas where no marsh was present. By collecting data on several physical parameters at each site (marsh size, elevation, surface slope and soil salinity), I was also able to investigate the relationships between these parameters and salt marsh function at both fringing and meadow marsh sites. This work was done as part of a National Estuarine Research Reserve Graduate Fellowship, and has been submitted as a report to the National Oceanic and Atmospheric Administration along with co-author Frederick T. Short.

I then conducted a field experiment to test the effects of marsh surface slope and north-south orientation on the growth of young *S. alterniflora* transplants. The site of the experiment was a salt marsh in Biddeford Pool, Maine. Pots containing *S. alterniflora* plants in soil commonly used in salt marsh construction projects were buried in the marsh at different slopes and orientations and a number of growth parameters were measured over the course of the growing season. The impetus for this experiment came from observations made in natural fringing marshes, where the growth and production of marsh plants was greater on flatter marshes than on steeply sloping marshes. The results of this experiment are presented in Chapter III.

Chapter IV summarizes my study of six constructed salt marshes in the Great Bay Estuary. The method used for selecting reference sites is described, and a comparison is made between the constructed and reference sites for four ecological functions (primary production, maintenance of plant biodiversity, soil organic matter accumulation, sediment filtration and trapping). Trajectory models were also developed for the four functions assessed. These models can be used to predict the functional development of constructed sites; that is, to show patterns of development and to estimate the time that will be required for constructed sites to reach the level of function observed in natural fringing salt marshes in the Estuary. I was invited to submit Chapter IV as an article to *Restoration Ecology*, a peer-reviewed journal, with co-author Frederick T. Short. The article was submitted in May 2000 and is now in review.

Funding for this research was provided by the NOAA National Estuarine Research Reserve Program, the New Hampshire Port Authority, the University of New Hampshire and the University of New England.

CHAPTER II

FUNCTIONS AND VALUES OF SALT MARSHES IN NORTHERN NEW ENGLAND: A COMPARISON OF FRINGING MARSHES AND MEADOW MARSHES

I. Introduction

Salt marshes are important estuarine habitats on the east coast of the United States, and 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 1992; Cook et al. 1993). Maine and New Hampshire have thousands of acres of salt marsh, and yet they have been studied much less than Atlantic coast marshes further south. Jacobson et al. (1987) identified 20% of Maine's tidally influenced coastline to be salt marsh habitat, totaling 7,900 ha (19,500 acres), and Cook et al. (1993) estimated that salt marshes in New Hampshire total 3,378 ha (7,500 acres).

Our current understanding of salt marsh ecology comes from studies of large meadow marsh systems, which are typically associated with barrier beaches and have direct access to the Atlantic Ocean (Ward et al. 1993). The coasts of Maine and New Hampshire include several of these large marsh systems as well as a large number of small marshes, sometimes referred to as fringe or fringing marshes (Cook et al. 1993; Bryan et al. 1997). Jacobson et al. (1987) found that nearly half of the marshes in Maine are 0.026 km^2 (6.4 acres) or smaller. Although no universal definition exists for fringing marshes, they have been described as relatively narrow estuarine marshes that form in protected areas along the edges of rivers and bays (Cook et al. 1993; Bryan et al. 1997). Fringing salt marshes are in need of study not just because there is little known about their role in the estuary, 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 impact their ecology unintentionally.

Both Maine and New Hampshire have laws that protect salt marshes. In NH, RSA 482A established the tidal buffer zone, which extends 100 feet above the highest observable tide line. It requires that a permit be issued for any activities that impact tidal wetlands. In Maine, salt marshes are protected under the Mandatory Shoreland Zoning Act (38 M.R.S.A, Section 435-449), which regulates land use activities within 250 feet of coastal wetlands, and the Natural Resource Protection Act (38 M.R.S.A. 480-A to 480-Z), which regulates activities in coastal wetlands and requires a permit for most activities in them. In spite of these laws, human-caused impacts to fringing marshes often go unreported, and their small size makes these impacts easy to overlook.

Although much is known about the ecology of larger meadow marshes, little research has been done to assess the functions and values of fringing marshes. The purpose of this study was to compare the functions and values of fringing marshes to those of larger, meadow marshes and for some functions, to shoreline areas where no marsh was present. We chose to use a "functions and values" approach to studying salt marshes for two of reasons. First, indicators of salt marsh functions can be measured objectively and are quantifiable. Second, functions are linked to values, to which the general public can relate. The distinction between functions and values is an important one. Functions are ecosystem activities or processes that occur over time and do not depend on societal perceptions; that is, they continue to occur whether or not people care about them (Brinson and Rheinhardt 1996). Values are things that people care about because they are "worthy, desirable or useful to humans" (Mitsch and Gosselink 1993). Citizens can more easily understand the concept of wetland values than the concept of wetland functions, and values often weigh heavily in decisions concerning the future of coastal resources. Based on past experience and the scientific literature we developed a list of the functions and values of New England's salt marshes (Table 1). We then selected several of these for study.

Our specific objectives were to: (1) measure several of the ecological functions of fringing salt marshes and meadow salt marshes, including (a) primary production, (b) soil organic matter accumulation, (c) maintenance of plant biodiversity, (d) filtration/trapping of sediments, and (e) dissipation of physical forces of waves; (2) compare these ecological functions (and their associated values) in fringing salt marshes and meadow salt marshes; and (3) determine how marsh physical characteristics (size, elevation, surface slope and soil salinity) are related to these marsh functions. Our hypotheses were (1) that the functions of fringing marshes are similar to those of meadow marshes, and (2) that there exist correlations between the physical characteristics and the ecological functions of the marshes studied.

II. Materials and Methods

A. Site Selection

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). Marshes with a substantial amount of freshwater input (indicated by soil salinity levels less than 20 ppt) were not included in this study. Both fringing and meadow marshes occupy areas that are protected from the direct wave energy of the ocean. The fringing marshes chosen are all located along the edges of rivers (SRF, YRF), bays or coves (BPF, ICCF, LHF), and the meadow marshes are found behind barrier beaches (DIM, LRM, MRM, BPM) or

Table 1. Functions and values of New England salt marshes (modified from Short et al. 2000).

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

adjacent to tidal creeks (SCM) (Fig. 3). All of the meadow marshes are naturally divided into sections by large creeks or rivers; we selected one of these sections for study in each meadow marsh.

B. Physical characteristics of fringing and meadow marsh sites

1. Sampling design

Samples were collected on each marsh site according to a stratified random sampling design. The proportion of high marsh area to low marsh area was determined for each site using 1:2400 scale aerial photographs that were then ground truthed in the field. A total of nine quadrats (1 m^2) were then randomly distributed between the high and low marsh in proportion to these areas. In fringing marshes, an x-y coordinate system was used to locate the random points. In meadow marshes, a latitude/longitude grid was placed over a base map of the marsh area and then nine random points were chosen from the grid. These points were then located in the field using global positioning system technology (GPS). Pannes and creeks were avoided. Soil porewater salinity, surface elevation and percent surface slope were measured at each of the nine quadrats per site. The distance of each quadrat from the water's edge was also recorded.

2. Physical characteristics measured at all sites

a) Salinity

Soil porewater was extracted using soil sippers made of 0.64 cm (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 determined using a refractometer. Samples were taken twice at each site, once in July and once in August. The salinity readings on the two dates were averaged.

b) Elevation

Elevations of all quadrats were determined using a Meridian L6-20 level and stadia pole. The relative elevations of all quadrats on a site were first measured by

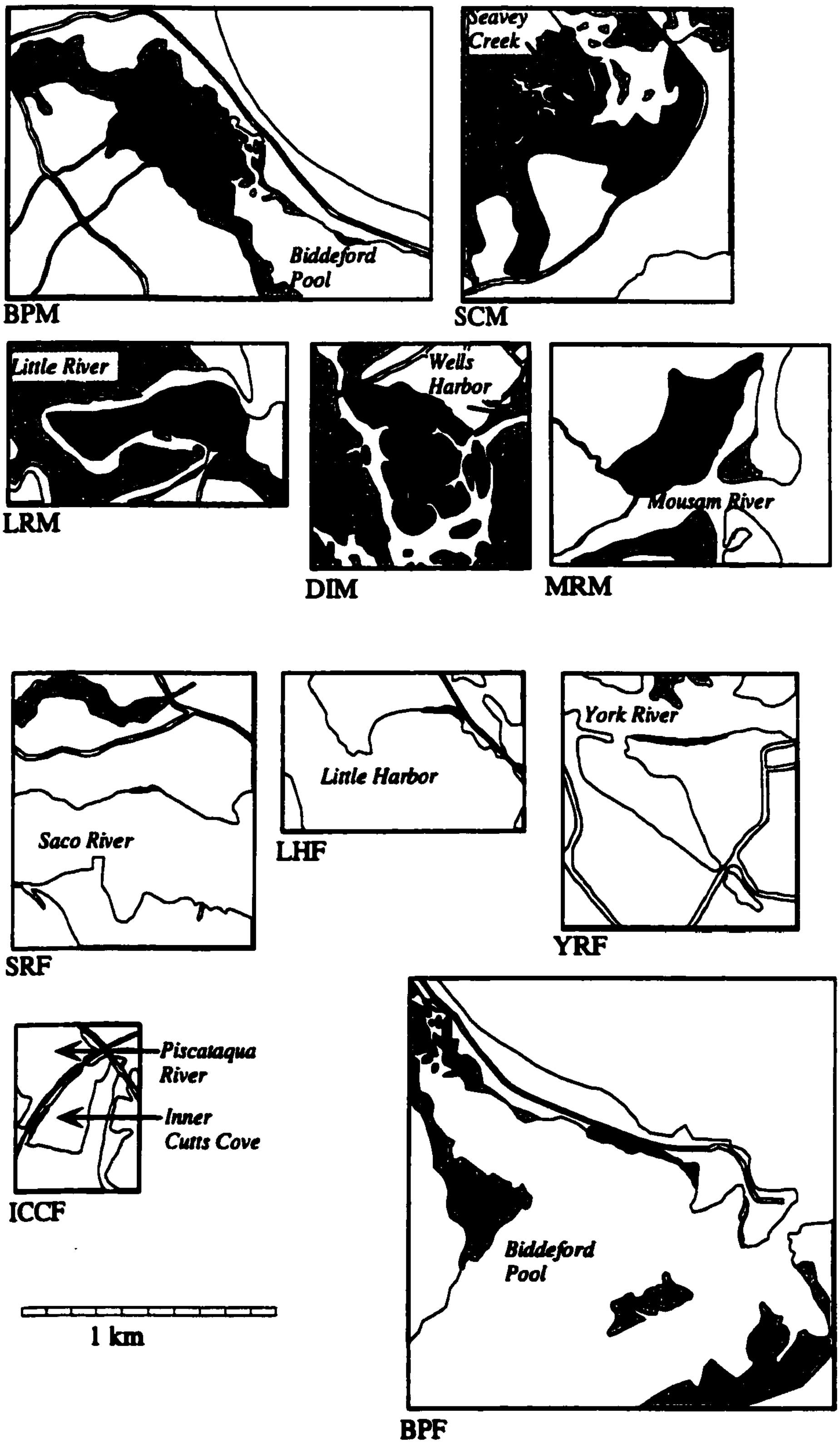


Figure 3. Relative sizes of five meadow and five fringing marsh sites (all shown at the same scale). Study sites are dark grey; upland is light grey; surrounding salt marshes are medium grey.

surveying from the quadrats to a relative benchmark nearby each site. These relative benchmarks were then tied into a high tide elevation on one date, which allowed for comparison of elevations between all sites. To determine the high tide line, three stakes painted with water-soluble paint were placed in each of the ten marsh sites before high tide (3.6 m (11.9') 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 m elevation.

c) Surface slope

Surface slope was measured at each quadrat in a direction perpendicular to the water's edge using a meter tape and a water level attached to a garden hose. The difference in elevation (rise) between two points approximately one meter apart was measured, and then a line level and meter tape were used to determine the horizontal distance (run) between the two points. The percent surface slope at each quadrat was then calculated.

d) Distance to edge

The distance from each quadrat to the water's edge was measured using a 50 m tape or a Lytespeed 400 rangefinder.

e) Area

The area of each site was determined from U.S.G.S. topographic maps with NIH Image 1.47 software, aerial photographs (1:2400) and field measurements. Perimeters of each site were digitally traced from the topographic maps, then adjusted using measurements made in the field. At smaller fringing marsh sites, marsh length and width (the mean of nine random points) were measured with a 50 m tape. A Lytespeed 400 rangefinder was used in meadow marshes to check distances along transects running from notable landmarks to the upland edge. Areas were then calculated using the Image software from the field corrected digital maps.

3. Analysis of physical characteristics data

Means and standard errors of the nine data points for each of the physical characteristics (a-d) above were calculated for each marsh site. Means of the ten sites were compared using Analysis of Variance (ANOVA) and then pairwise comparisons were made with Student-Newman-Keuls or Scheffe's S tests. (Scheffe's S test was used to compare mean site elevations, because variances were not homogeneous.) The overall means and standard errors for meadow and fringing marsh types were also determined and compared using ANOVA.

C. Assessment of marsh functions

1. Functions measured/metrics employed

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. An indicator is a variable closely associated with a particular wetland function. Indicators should be sensitive enough to represent functional performance and be relatively easy to measure (Kentula et al. 1992). Measures of wetland structure are often used as indicators instead of direct measures of function due to economic and time constraints. However these structural measurements can become measures of function if they are made over time (Kentula et al. 1992). The functions we assessed and the corresponding indicators we used to measure them are listed in Table 2.

a) Primary production

The peak standing crop (including both live aboveground and live belowground plant biomass) served as an indicator for the function of primary production. Samples were collected from nine stratified random quadrats at each marsh site (the same quadrats from which the physical characteristic data were collected).

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

Function	Indicator
Primary production	Annual standing crop (above and belowground biomass/area/time)
Soil organic matter accumulation	Soil organic content over time (grams organic matter/area/time)[1]
Maintenance of plant diversity	Species richness (no. species/site); Relative abundance (percent cover of plant species)[1]
Sediment filtration, trapping and binding	Sediment accumulation on discs (grams sediment/area/time)
Dissipation of physical forces	Wave profiles from video monitoring (reduction in wave height/distance from marsh edge)

[1] These measurements were made only once in this study, so were not tracked over time.

Aboveground biomass was sampled at the end of the growing season (late August 1997) by clipping all vegetation in a 0.25 m^2 quadrat. Live plants were separated from dead material and then dried at 60°C for 48 hr and weighed.

A sediment core (20 cm deep, 3.5 cm diam.) was taken from each quadrat after it had been clipped. Samples were then washed on a 2 mm screen, live roots and rhizomes were separated from dead material and then dried at 60°C for 48 hr and weighed to determine belowground biomass (Gross et al. 1991).

b) Soil organic matter accumulation

A one-time measurement of the soil organic matter content was made in August 1997. One core (15 cm deep, 3.5 cm diam.) was taken from each of the nine quadrats per site, and the amount and percent of organic matter in the sediment from the 15 cm core was determined from weight loss upon combustion in a muffle furnace (450°C for 4 hr) (Craft et al. 1991). Samples were collected from nine stratified random quadrats at each marsh site, the same quadrats from which the physical characteristic data were collected.

c) Maintenance of plant diversity

The species richness and relative abundance of each of the higher plants were assessed once at each site, in late July 1997. Percent cover of all species in 1 m^2 quadrats was estimated visually using the following cover classes: 0%, $0\% < x \leq 1\%$, $1\% < x \leq 5\%$, $5\% < x \leq 10\%$, $10\% < x \leq 20\%$, and continuing above 20% in 10% increments up to 100%. Total percent cover per quadrat could not exceed 100%.

The numbers of quadrats sampled on fringing and meadow marshes were based on preliminary sampling and calculation of running averages for small and large marsh sites. The results of this initial analysis indicated that the minimum number of quadrats needed on fringing and meadow marsh sites were 10 and 30, respectively, in order to include the majority of plant species on the two different sized sites. These quadrats were then distributed in a stratified random manner, according to the proportion of high and low marsh at each site.

Physical data, including percent surface slope, soil porewater salinity, distance to the water's edge and elevation were also collected at each of the ten quadrats at fringing marsh sites and 30 quadrats at meadow marsh sites.

d) Sediment filtration and trapping

This function was assessed by measuring the amount of sediment accumulated on sediment traps (discs) over ten days in mid-August 1997. 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 6 inch long metal sod staples (Fig. 4).

Five sediment traps were distributed in a stratified random manner on each site, according to the amount of high and low marsh present. Five additional traps were placed on the marsh surface 1 m from the water's edge. These traps were randomly distributed along the seaward edge of each marsh site. Three traps were also placed in areas where no marsh was present, adjacent to the five fringing marsh sites. Discs were collected after two weeks, dried at 60°C for 48 hr and weighed. In addition, the elevation and distance to the water's edge of each trap were measured, and the number of plant stems and the percent cover of plant species present in a 1 m^2 quadrat around each trap on the marsh surface were recorded.

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 beyond the marsh grass so that the base of the bottle was on the ground 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 μm glass fiber filters, then drying the filters plus sediment at 60°C for 48 hours.

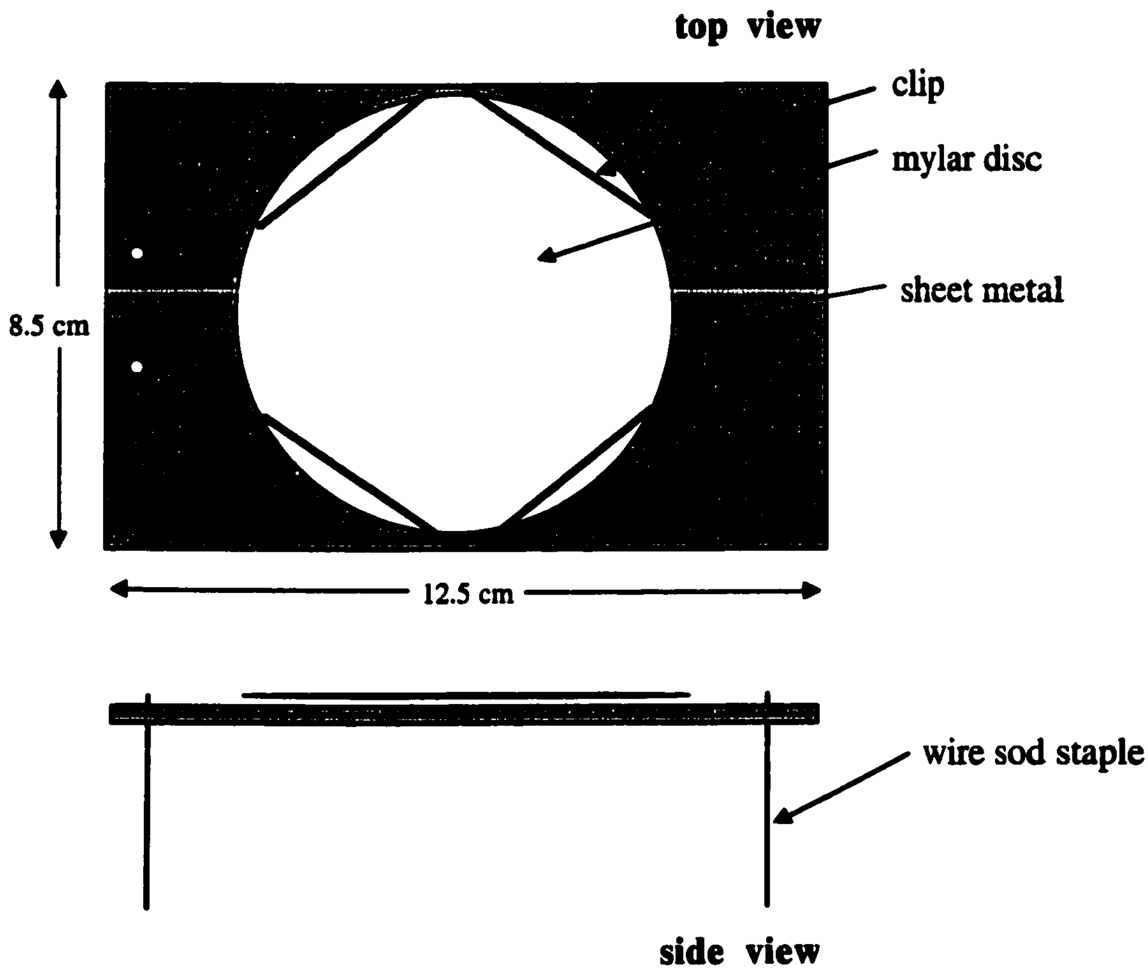


Figure 4. Sediment trap with mylar disc for use on marsh surface. Traps are placed flush with the marsh surface and held in place by sod staples.

e) Dissipation of physical forces of waves

The energy of waves moving across a marsh is proportional to the square of the height of those waves (Denny 1988). Therefore to assess how well fringing and meadow marshes dissipate wave energy we looked at the difference in wave heights from the marsh/water edge to 5 m and 7 m into the marsh along a transect perpendicular to the edge. This was done at three of the fringing marsh sites, three of the meadow marsh sites, and three areas where no marsh was present.

Three transects were laid out at each site, evenly spaced along the marsh/water edge. Stakes with meter sticks attached were placed at 0 m, 5 m and 7 m along each transect. Waves were generated by the wake of a 17' aluminum boat and then videotaped simultaneously at 0 m and 5 m, then at 0 m and 7 m. Waves from the boat were filmed three times (called 'takes') at 0 m and 5 m and three times (takes) at 0 m and 7 m along each transect. Videotapes were later viewed frame-by-frame (30 frames/sec.) and wave peaks and troughs were recorded for each take at 0 m and at 5 m 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 m and 5 m, and from 0 m to 7 m were calculated for the 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 m and 5 m, and from 0 m to 7 m. Finally, percent wave height reduction values (maximum and three wave) obtained for the three transects were averaged to determine means for each fringing marsh, meadow marsh and 'no marsh' site.

The percent surface slope from 0-5 m and from 0-7 m was measured along each transect. In addition, a 0.5 m^2 quadrat was placed around each meter stick (at 0, 5 and 7 m) and the plants within the quadrat were clipped to within 2 cm of the soil surface. Plants were later sorted into species and the number of stems of each species in the 0.5 m^2 area counted. Ten plants per species were randomly selected and their height and stem diameters measured. All plant material collected in each quadrat (live and dead) was then dried at 60°C for 48 hr. and weighed to determine aboveground biomass. The average number of stems, stem diameter and dry weight per 0.25 m^2 from 0-5 m were calculated by averaging the values for the 0 m and 5 m quadrats. Averages were also calculated for the 0-7 m distance along each transect. The depth of the water at the time of filming was also recorded at the 0 m, 5 m and 7 m points along the transects.

2. Comparison of fringing marsh functions to meadow marsh functions.

a) Correlations with physical characteristics

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. Scatterplots were drawn comparing the quantitative assessment for each function with each of the physical characteristics investigated for that function. Correlation coefficients were then calculated for each function-physical characteristic pair. Results of these correlations aided in the choice of which variables to use as covariates in the means comparisons described below.

b) Means comparisons

For each of the functions in Table 2 and their associated metrics, the 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 physical forces. Analysis of Variance (ANOVA) or Analysis of Covariance (ANCOVA) was then employed to compare the mean values from the fringing marsh sites with those of the meadow marsh sites for each function. If data were collected at 'no marsh' sites, these were included in the means comparisons as well.

c) Plant diversity

Data collected to assess the maintenance of plant diversity function were analyzed to compare the number of species per site, species density, and evenness (E) of higher plant species in meadow and fringing marshes. The percent covers of *Spartina alterniflora* and of the high marsh species *Juncus gerardii*, *Puccinellia maritima* and *Spartina patens* were also calculated for each meadow marsh site and each fringing marsh site. Average values for each of these plant community attributes were then calculated and compared using ANOVA. Calculations were based on ten random quadrats per fringing marsh site and ten random quadrats per meadow marsh site when calculating plant species evenness (E), as this diversity parameter requires an equal sample size to compare two communities. For the other indicators of plant species diversity, fringing marsh means are based on ten quadrats and meadow marsh means on thirty quadrats, although the means of ten meadow marsh quadrats are also presented. The rationale for using either ten or thirty quadrats when calculating mean values in meadow marshes is explained further in the Discussion section.

III. Results

A. Site selection

The five fringing and five meadow marsh sites selected for study are located from the Saco River, ME to Little Harbor, NH (Fig. 1). Sites and locations are listed in Appendix Table A1. The tidal range for the area is approximately 9 feet, with two high and two low tides per day. All ten sites included distinct low marsh areas dominated by *Spartina alterniflora* and high marsh areas dominated by *Spartina patens*, *Juncus gerardii*, *Distichlis spicata* and/or *Puccinellia maritima*. There was a range in the salinity of the soil porewater sampled at the sites, as those located along the edges of large freshwater rivers like the Saco and the York rivers receive more freshwater input, but all sites had spring (May-June) porewater salinities greater than 19 ppt. The plant communities of these sites therefore included very few species that could not tolerate saline soils.

B. Physical characteristics of fringing and meadow marsh sites

1. General differences

The average soil salinities of the five meadow and the five fringing marshes (calculated as means of five sites) were significantly different from each other, as were the average surface slopes, elevation and distance to the water's edge of the nine quadrats ($P < 0.05$) (Fig. 5). The average area of meadow marshes was significantly greater than that of the fringing marshes (Fig. 5i). Figure 5 also shows the means and standard errors of the nine data points for the physical characteristics measured at each marsh site. Means and standard errors for each marsh site are listed in Appendix Table A2.

2. Physical characteristics measured at all sites

a) Salinity

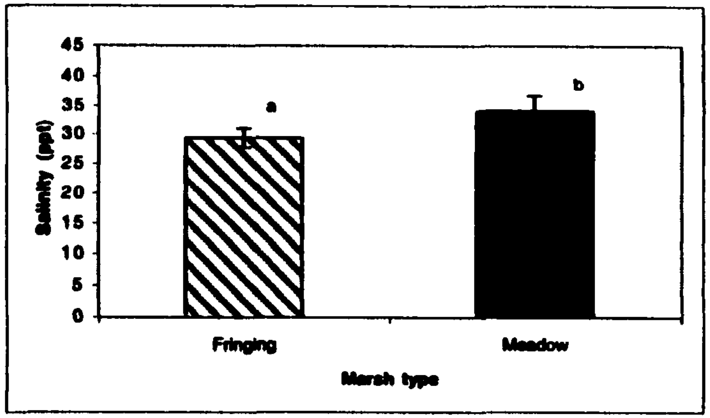
All ten sites had statistically similar porewater soil salinity levels except for one fringing marsh on the Saco River (SRF), which had significantly lower salinity than the other sites (Fig. 5b). However, most of the fringing marshes had lower porewater salinities than the meadow marshes; there was a significant difference between the average soil salinities of the five meadow marshes and the five fringing marshes (P=0.0484) (Fig. 5a).

b) Elevation

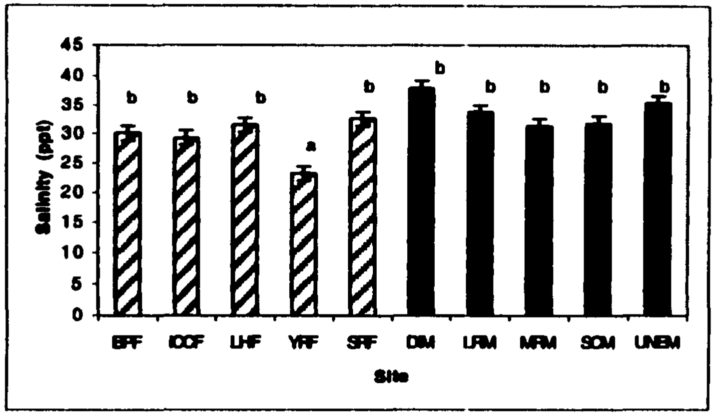
Figure 5d shows the differences in the mean elevations of the ten sites. Two fringing marsh sites, one in Biddeford Pool (BPF) and one on the York River (YRF), were significantly lower in elevation than all of the meadow marsh sites, which had similar mean elevations. Comparing the five meadow marshes to the five fringing marshes we found that the meadow marshes had a significantly higher mean elevation (ANOVA, P=0.0038) (Fig. 5c).

c) Surface slope

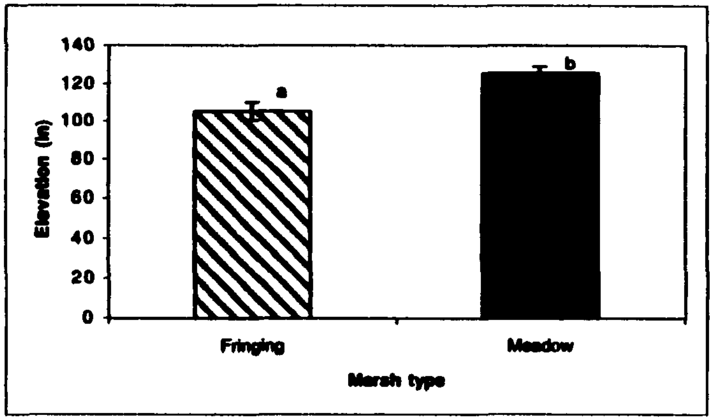
The percent surface slopes of all the fringing marshes were greater than those of the meadow marsh sites (Fig. 5f). The average slope for all five fringing marshes (9.2%)



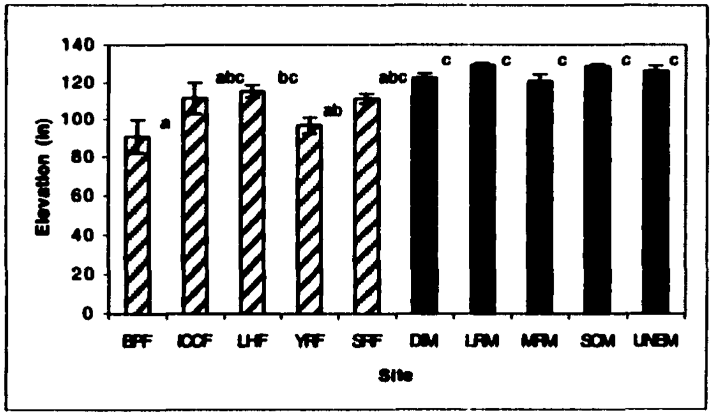
a. Mean porewater salinities of five fringing marsh and five meadow marsh sites. Means are significantly different from each other (ANOVA, p= .0484).



b. Porewater salinities at each site. Means are significantly different from each other ANOVA, p=.0003). Pairwise comparisons made with Student-Newman-Keuls (SNK).

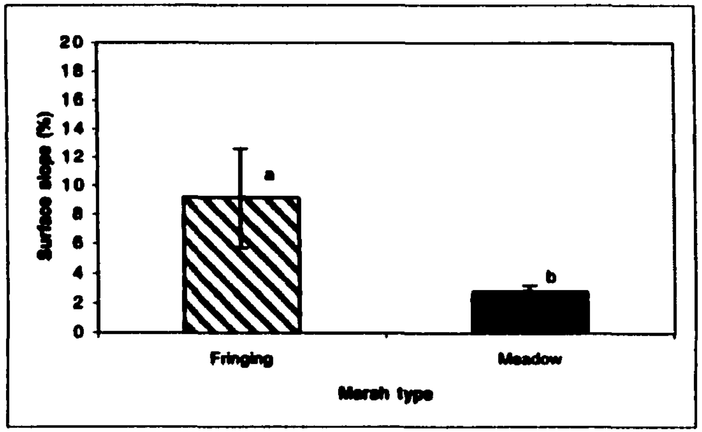


c. Mean elevations of five fringing marsh and five meadow marsh sites. Means are significantly different from each other (ANOVA, p= .0038).

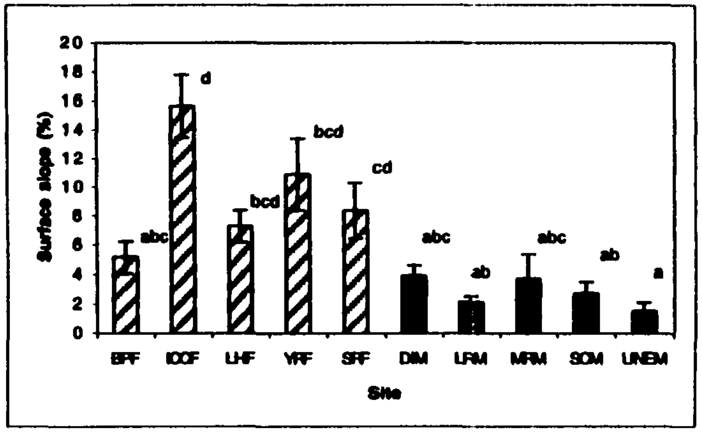


d. Elevations at each site. Means are significantly different from each other ANOVA, p=.0001). Pairwise comparisons made with Scheffe's S.

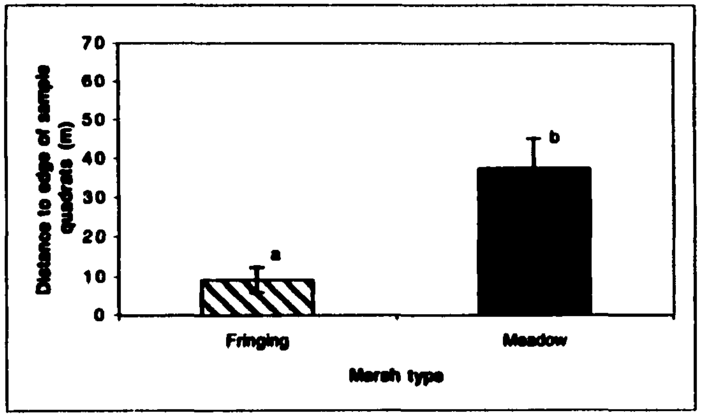
Figure 5a-d. Means of physical characteristics for each marsh type (a,c) and at each site (b,d). Bars in each graph followed by the same letter are not significantly different from each other according to the pairwise comparison listed. Error bars are ±1 SE.



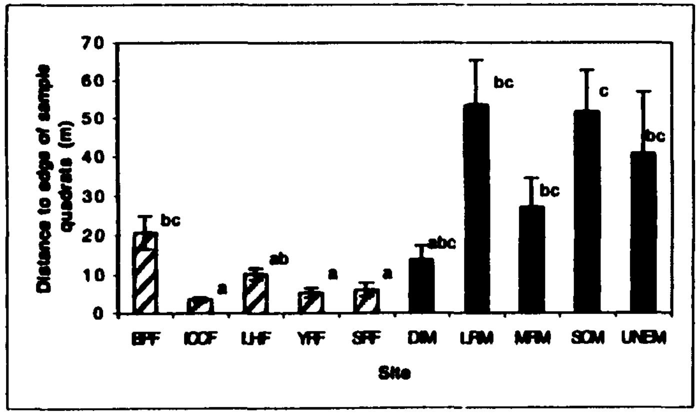
e. Mean surface slope of five fringing marsh and five meadow marsh sites. Means are significantly different from each other (ANOVA, p= .0012, log transformed data).



f. Percent surface slope at each site. Means are significantly different from each other ANOVA, p=.0001, log transformed data). Pairwise comparisons made with SNK.

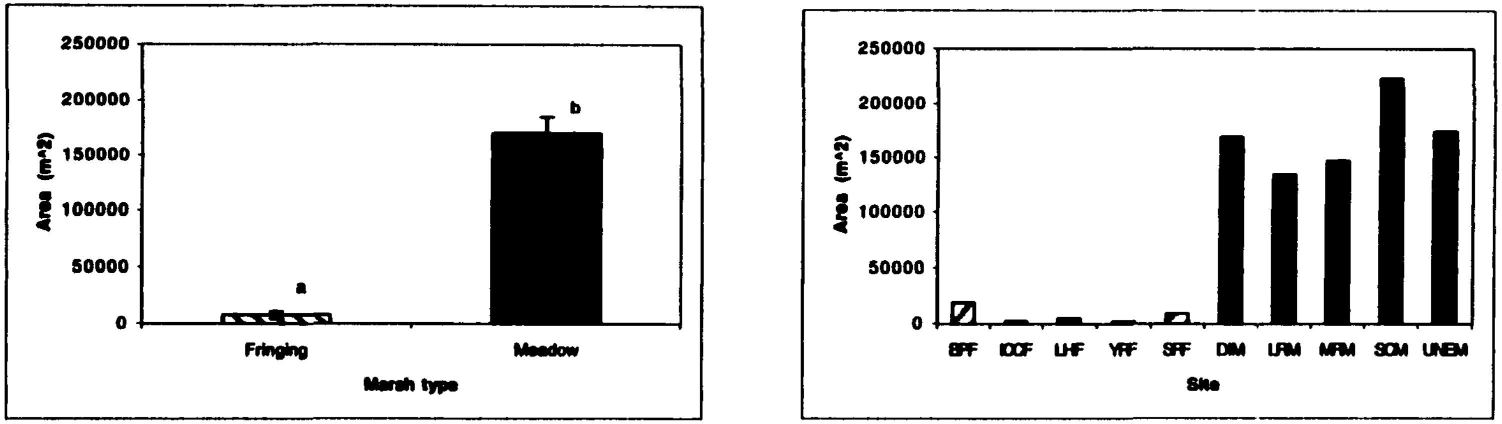


g. Mean distance to edge of nine quadrats at five fringing marsh and five meadow marsh sites. Means are significantly different from each other (ANOVA, p= .0056, log transformed data).



h. Mean distance to edge of nine quadrats at each site. (Means are significantly different from each other ANOVA, p=.0001, log transformed data). Pairwise comparisons made with SNK.

Figure 5e-h. Means of physical characteristics for each marsh type (e,g) and at each site (f,h). 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.



i. Mean areas of five fringing marsh and five meadow marsh sites. Means are significantly different from each other (ANOVA, p= .0001, square root transformed data).

j. Areas of fringing and meadow marsh sites.

Figure 5i-j. Means of physical characteristics for each marsh type (i) and at each site (j). 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.

was significantly greater than that of the meadow marshes, which was only 2.8% (ANOVA, P=0.0018) (Fig. 5e).

d) Distance to edge

The average distance to the water's edge of the nine quadrats on most of the fringing marsh sites was less than the average distance to the water's edge of the nine quadrats on meadow marsh sites. The value for the fringing marsh in Biddeford Pool (BPF) was more like the meadow marsh site values, and one meadow marsh site (DIM) had a mean distance to water's edge value similar to that of many of the fringing marshes (Fig. 5h). The overall mean value for the five fringing marsh sites (9.1 m) was also significantly different (P=0.0056) from the mean of the five meadow marsh sites (37.4m) (Fig. 5g).

e) Area

The average area of the five meadow marshes was significantly greater than that of the five fringing marsh sites (Fig. 5i).

C. Comparison of fringing marsh functions to meadow marsh functions

1. Primary production

a) Aboveground biomass

The slope of the marsh surface appears to affect the peak standing crop to a greater extent in fringing marshes than in meadow marshes (Fig. 6). Correlation analysis of the mean slopes of the five fringing marshes with the sites' mean aboveground biomass values showed that these variables were highly correlated (r=0.935). The correlation was not as great in meadow marshes (r=0.336). It is interesting to note that this relationship between surface slope and aboveground biomass in fringing marshes was much stronger at the site level than at the quadrat level. Site level values represent each site as a whole, and were calculated as the mean of the nine random quadrats at each site. Quadrat level correlations were calculated using biomass and slope values from all

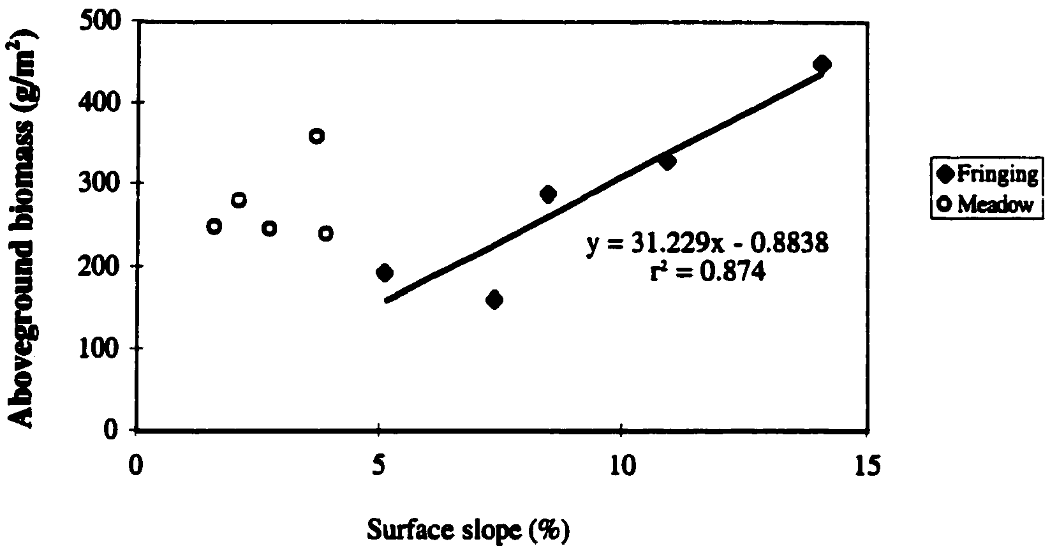


Figure 6. The relationship between site-averaged percent surface slope and aboveground biomass for the five fringing and five meadow marsh sites. The line shows the linear regression of fringing marsh sites only.

nine quadrats at each site. The correlations between aboveground biomass and surface slope for fringing marshes calculated at the quadrat level (9 quadrats x 5 sites = 45 quadrats) revealed a weak relationship, with r=0.384. The correlation at the quadrat level was also weak for meadow marshes, with r=0.310. Correlation values are presented in Appendix Table A3.

We tested the effect of marsh type (fringing vs. meadow) on the amount of aboveground biomass present at harvest and found no difference between the two marsh types (ANOVA, P=0.9239) (Fig. 7). Also, the variability in aboveground biomass from site to site appeared greater for fringing marsh sites than for meadow marsh sites. The mean and standard errors of fringing marshes and meadow marshes were 285 +/- 52 g/m^2 and 274 +/- 22 g/m^2, respectively. The mean values for all ten sites are listed in Appendix Table A4.

b) Belowground biomass

As stated earlier, the mean slope of the fringing marsh sites was greater than that of the meadow marshes. Percent surface slope may affect belowground biomass production in fringing marshes. Belowground biomass values were greater in more steeply sloped fringing marshes than in flatter sites (r=0.939)(Fig. 8a). In the flatter meadow marshes, there was no correlation between surface slope and belowground biomass (r=0.083). Similar to aboveground biomass, the correlation between belowground biomass and slope in fringing marshes appears to occur only at the site level, and not at the quadrat level. There was no correlation between belowground biomass and surface slope in fringing marshes at the quadrat level, where r=0.0196 (Appendix Table A3).

The mean elevation of a site may be an important factor in its rate of belowground production, as illustrated in Figure 8b. Correlation analysis between the mean elevations of the ten sites and their belowground biomass values showed a correlation of r=0.462. Again, this relationship did not appear to hold at the quadrat level. When the elevations

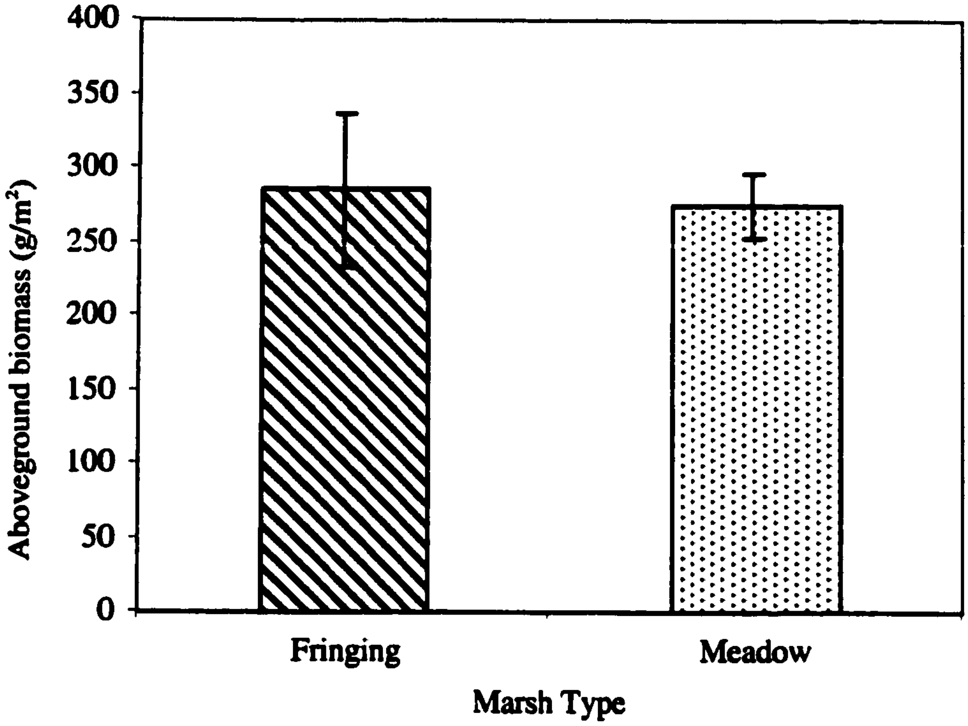
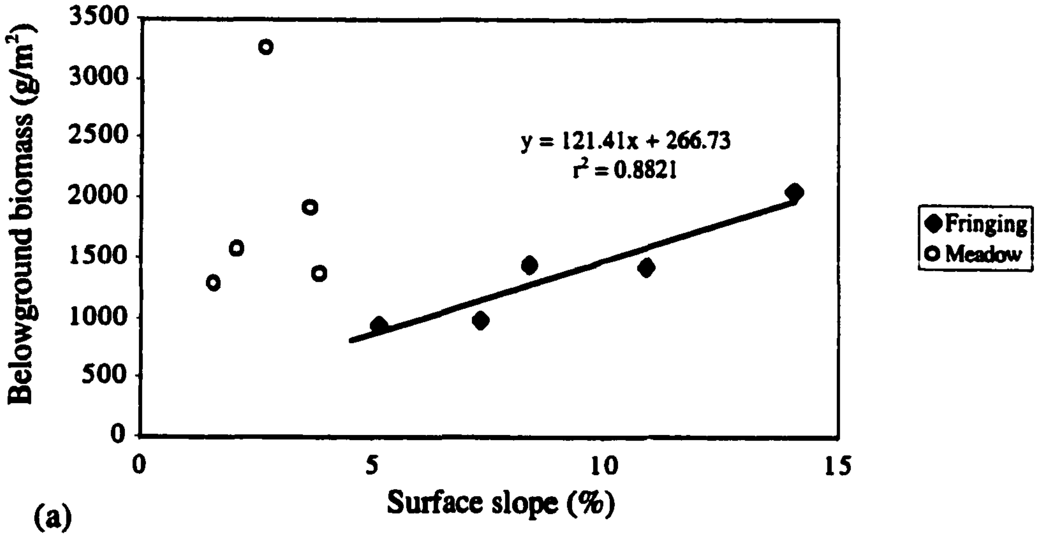
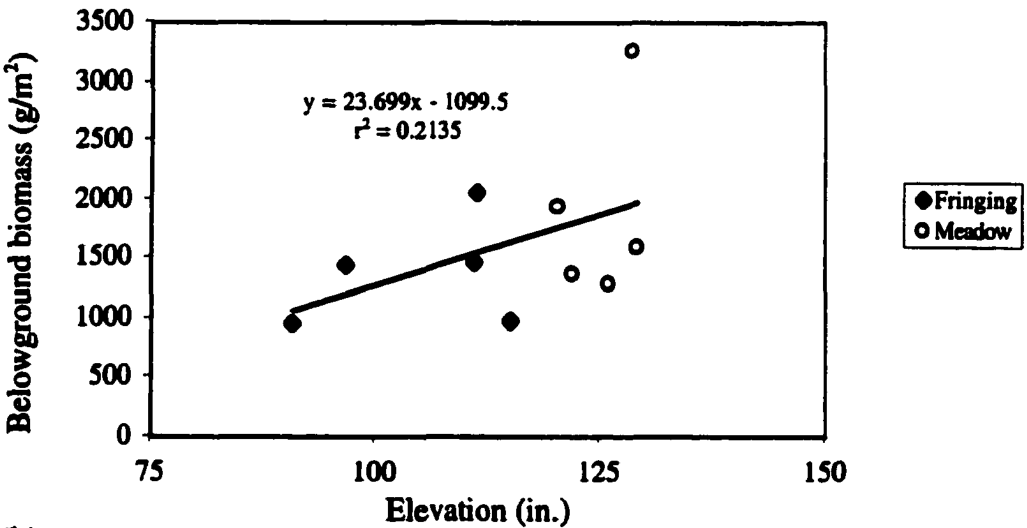


Figure 7. Aboveground plant biomass of fringing and meadow salt marsh sites. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the two means ($P = 0.9239$).



(a)



(b)

Figure 8. The relationships between belowground biomass and (a) percent surface slope and (b) elevation at the five fringing and five meadow marsh sites. The regression line in (a) is for fringing marsh sites only. The regression line in (b) is for both fringing and meadow marsh sites.

of the individual quadrats were correlated with the belowground biomass values for those quadrats, r=0.210 (9 quadrats x 10 sites = 90 quadrats) (Appendix Table A3).

To determine if there was a difference in the belowground biomass of fringing and meadow marsh sites, we compared the site type means with ANOVA. Results showed no significant difference in the mean belowground biomass of meadow and fringing marshes (P=0.1951, 1/x transformed data) (Fig. 9). The mean belowground biomass values for all ten sites are listed in Appendix Table A4. There was also no difference in the average total (aboveground and belowground) biomass between the meadow and fringing marsh sites (ANOVA, P=0.2929) (Fig. 10).

2. Soil organic matter accumulation

The percent organic matter content in the top 15 cm of meadow marsh soils was significantly greater than that of fringing marsh soils (Fig. 11). All five meadow marsh sites had higher mean elevations and a greater percent soil organic matter content than the five fringing marshes we studied. There was good correlation between the mean elevations of the ten sites and the mean percent soil organic matter content (r=0.801) (Fig. 12), although this relationship did not hold when fringing and meadow marshes were considered separately. The correlation was also fairly strong at the quadrat level, between the elevations of the 90 quadrats (all quadrats sampled in fringing and meadow marshes) and their percent soil organic matter content (r=0.619).

The total amount of organic matter in the top 15 cm per m^2 of marsh surface was also calculated, and found to correlate highly with percent soil organic matter values (r=0.954). Percent soil organic matter and total soil organic matter values for the ten sites are presented in Appendix Table A4. The mean percent soil organic matter was significantly greater in meadow marshes than in fringing marshes (P=0.0002). This was the case even after removing the variability due to elevation from the model (ANCOVA P=0.0202, elevation P=0.0011). The mean values for all ten sites are listed in Appendix Table A4.

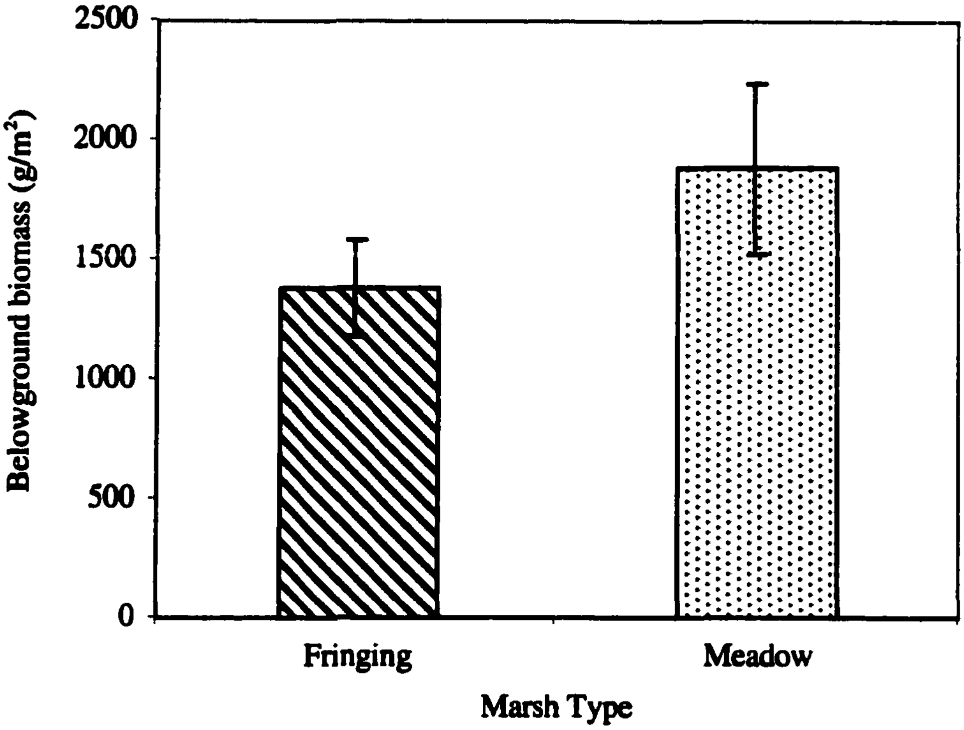


Figure 9. Belowground plant biomass of fringing and meadow salt marsh sites. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the two means ($P = 0.1951$, 1/x transformed).

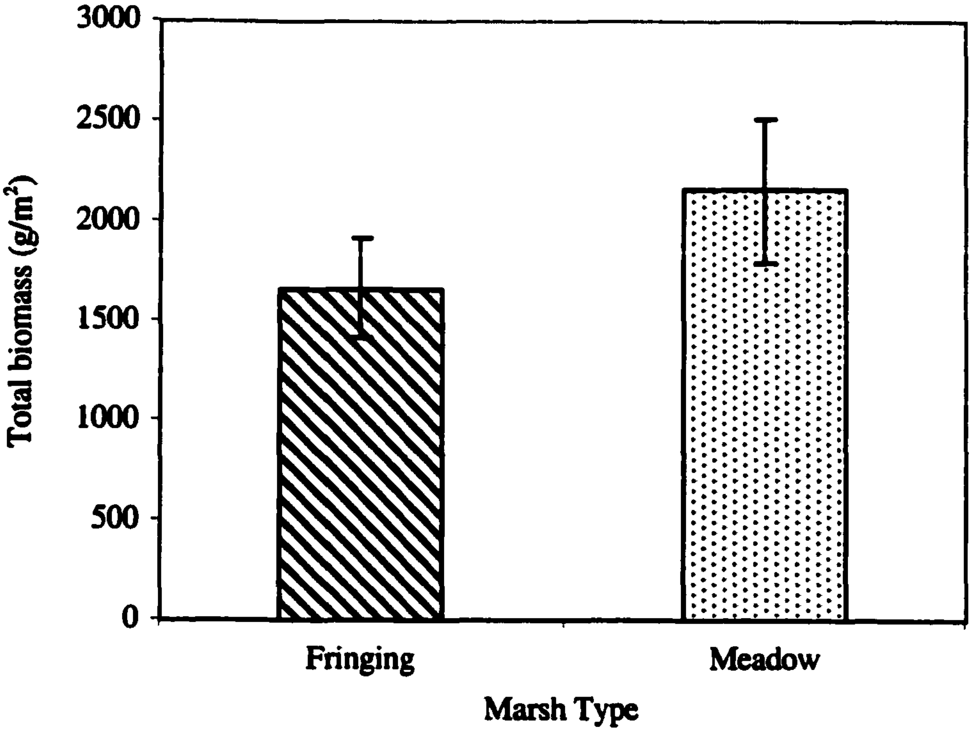


Figure 10. Peak season plant biomass of fringing and meadow salt marsh sites. Includes aboveground and belowground live biomass. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the two means ($P = 0.2929$).

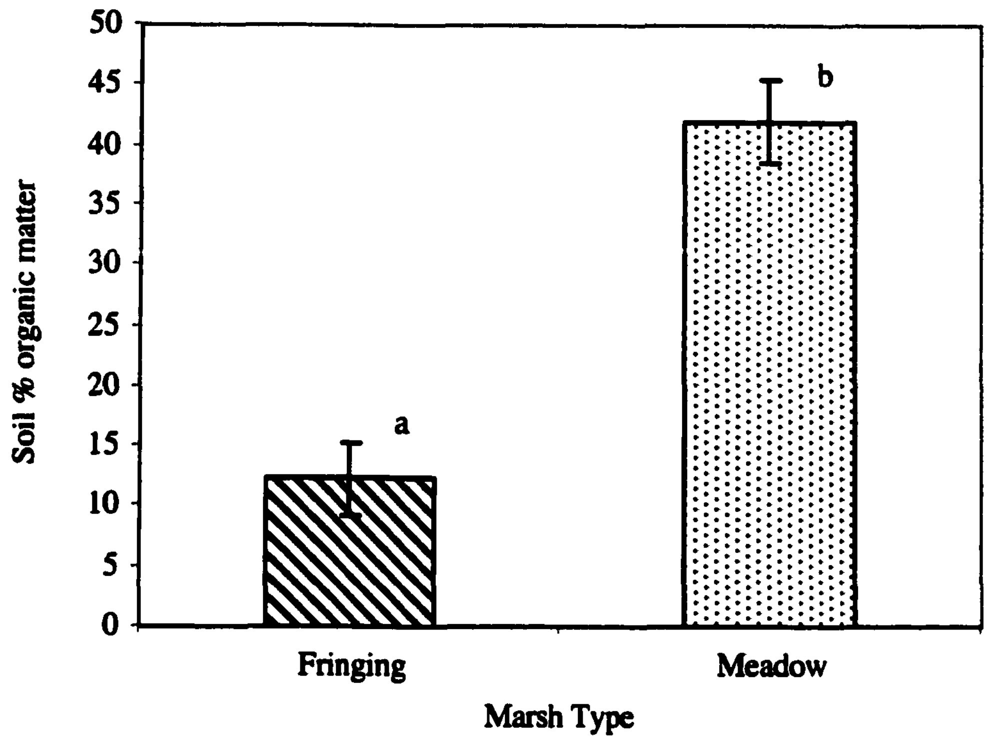


Figure 11. Percent organic matter content of fringing and meadow salt marsh soils. Error bars are +/-1 standard error from the mean of five sites. Means are significantly different ($P = 0.0202$, elevation covariate $P = 0.0011$).

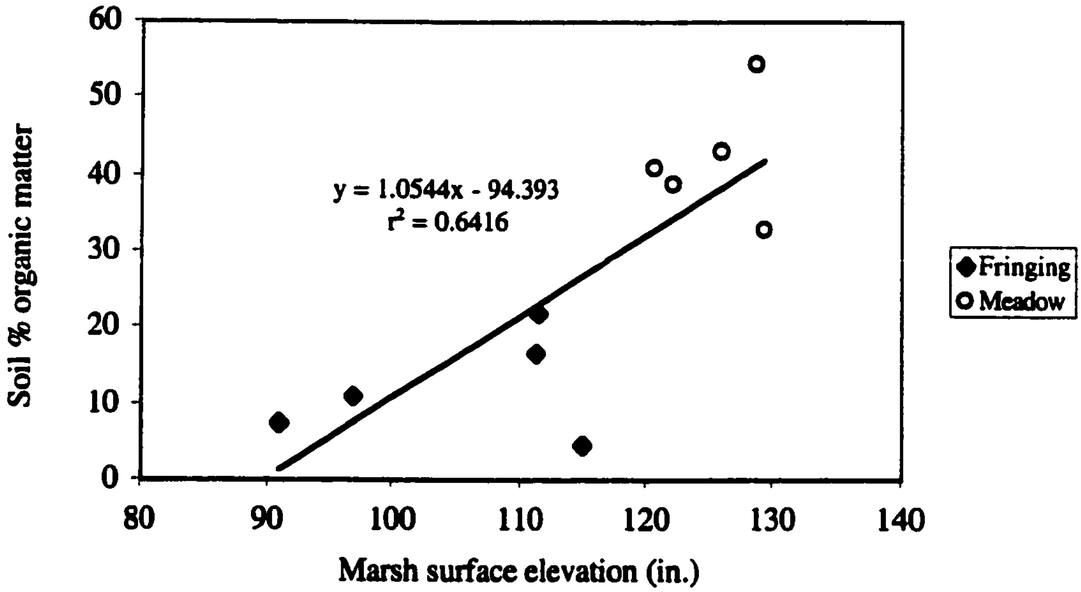


Figure 12. The relationship between marsh surface elevation and soil percent organic matter content for five fringing and five meadow marsh sites. Elevation units are inches above mean low tide. The regression line includes data from all ten marsh sites.

3. Maintenance of plant diversity

a) Number of species per marsh site

Using the full sample of ten quadrats in fringing marshes and thirty quadrats in meadow marshes, the number of plant species per marsh site (cumulative over all 10 or 30 quadrats) was greater for meadow marshes (15.6 +/- 2.7) than for fringing marshes (8.8 +/- 2.0)(ANOVA, P=0.0020). When an equal number of quadrats was sampled in fringing and meadow marshes (ten quadrats), species richness per site was still greater for meadow marshes, but this difference was not statistically significant (ANOVA, P=0.2792) (Table 3). If elevation was included as a covariate when comparing species richness in fringing and meadow marshes, meadow marshes had significantly more species whether the full sample of ten and thirty quadrats (ANCOVA, P=0.0006, elevation P=0.0120) or an equal sample of ten quadrats (ANCOVA, P=0.0122, elevation P=0.6338) was used in the analysis. These results indicate that both marsh size and elevation may influence species richness. A negative correlation between percent surface slope and species richness was also observed (Table A3).

b) Species density

Species density, the mean number of species per sampling unit, was greater in meadow marshes than in fringing marshes, regardless of whether ten or thirty quadrats were used to calculate meadow marsh values (Table 3). So the results reported here were calculated from ten quadrats in fringing marshes and thirty quadrats in meadow marshes. There were an average of 4.84 +/-0.4 species per m^2 in meadow marshes and only 2.84 +/-0.09 species per m^2 in fringing marshes (ANOVA, log transformed data, P=0.0001). Species density was positively correlated with the mean elevation (r=0.792) and negatively correlated with the percent surface slope of the quadrats sampled (r=-0.806) (Table A3). If species density in the two marsh types was compared using elevation as a covariate, there was still a significant difference between the two marsh types, even though the effect of elevation had been removed (ANCOVA P=0.0002, elevation

Table 3. Plant community characteristics of fringing and meadow marsh sites. Means and standard deviations are of five meadow marsh or five fringing marsh sites. Meadow marsh values in parentheses are based on thirty 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 ($p<.05$). H' is the Shannon-Weiner diversity index, and E is the index for evenness.

Characteristic	Fringing marsh		Meadow marsh	
	Mean	S.D.	Mean	S.D.
Species richness/site	8.8[a]	2.0	10.4[a] (15.6)[b]	2.3 (2.7)
Species density (#species/m^2)	2.84[a]	0.09	4.50[b] (4.84)[b]	1.0 (0.40)
H'	0.522[a]	0.119	0.537[a]	0.05
E	0.557[a]	0.115	0.536[a]	0.064
Percent cover PM,JG,SP,DS*	26[a]	12	53[b] (54)[b]	21 (10)
Percent cover *S. alterniflora*	35[a]	13	19[a] (16)[b]	16 (5)

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

P=0.0001, log transformed data). A similar result was found using slope as a covariate when comparing species density in fringing and meadow marshes (ANCOVA *P*=0.0002, slope *P*=0.0001, log transformed data).

c) Evenness

There was no difference in the distribution of individuals among the species on fringing and meadow marsh sites, as measured with $E = H'/H_{max} = H'/\ln S$ (Magurran 1988), an indicator of evenness (ANOVA, *P*=0.7214) (Table 3). This is based on ten quadrats sampled in both fringing and meadow marshes, as equal sample sizes must be used when calculating E. H' values (calculated to determine E) were also not significantly different between fringing and meadow marshes (Table 3).

d) Species by species comparison

Results presented here and in Table 3 are from ten sampled quadrats in fringing marshes and thirty sampled quadrats in meadow marshes. (Results from equal sample sizes are also reported in Table 3.) A comparison of the percent cover of the most dominant marsh plants in fringing and meadow marshes revealed some differences between these two marsh types. *Spartina patens*, *Juncus gerardii*, *Distichlis spicata* and *Puccinellia maritima* were the most prevalent species in the high marsh areas, so their percent cover values were combined for each site as a representation of the percent cover of common high marsh plants. This combined percent cover value was significantly greater in meadow marshes (54%) than in fringing marshes (26%) (ANOVA, *P*=0.0033). There was also a significant difference in the percent cover of *Spartina alterniflora*, the dominant low marsh species, with fringing marshes having more *S. alterniflora* (35%) than meadow marshes (ANOVA, *P*=0.0102, log transformed data) (Table 3). The percent covers of all plant species at all ten sites are listed in Appendix Table A5. In addition, all of the plant community characteristics (species density, evenness, etc.) for each site are listed in Appendix Table A6.

4. Sediment filtration and trapping

a) Correlations with physical data

In the group of traps placed 1 m from the water's edge of the marshes, one trap at DIM had an unusually large amount of sediment deposited on it (1847.89 g/ m^2 /day, compared to the next highest value of 0.92 g/ m^2 /day). 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 as an outlier and was discarded, so that the mean value for the sediment deposition rate at DIM was calculated from the remaining four sediment traps, and all correlations were calculated based on four traps for that site.

Of the physical characteristics measured at each sample quadrat, elevation was observed to correlate best with the amount of sediment deposited on the marsh surface. This relationship was observed at the quadrat level when considering all quadrats at fringing and meadow marsh sites, at traps randomly distributed on the marsh surface ($r=-0.635$) as well as those only 1 m from the edge ($r=-0.427$), although the latter relationship appears to be driven by a single data point (BPF). Elevation also correlated with the amount of sediment deposited at the site level when traps were randomly distributed on the marsh surface. Sediment deposition was less at sites with a higher mean elevation, at both fringing and meadow marsh sites (Fig. 13a, c).

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. However this was observed to occur only in fringing marshes, not in meadow marshes (Fig. 13b, d), and again this correlation was driven by the value at one fringing marsh site in Biddeford Pool (BPF).

In addition, we measured the percent cover of plant species around sediment traps to see if this biological characteristic was related to the amount of sediment deposited.

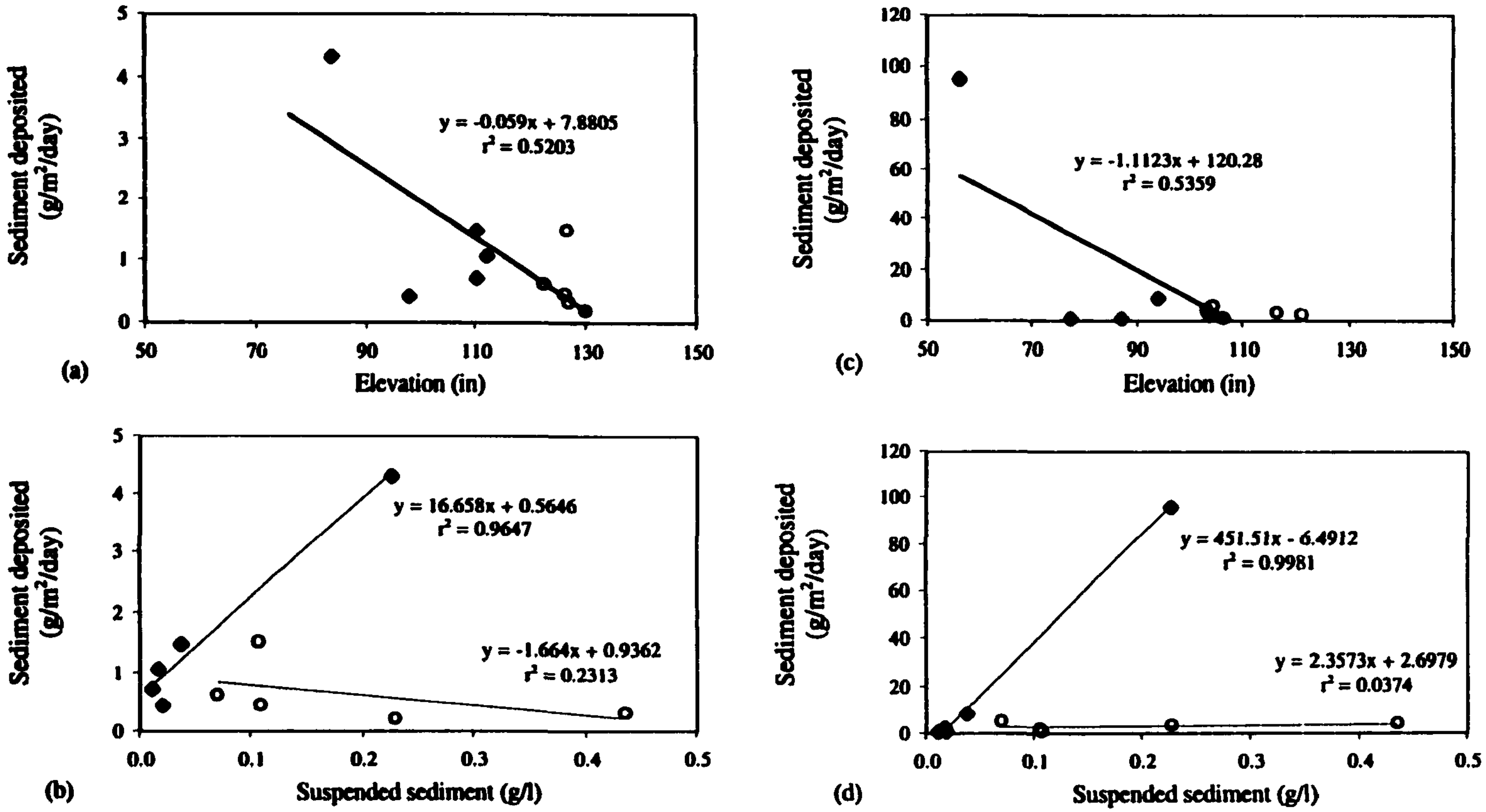


Figure 13. Physical characteristics that may influence sediment deposition on the marsh surface. Relationships between marsh surface elevation and sediment deposition on traps randomly distributed (a) and placed 1m from the water's edge (c), and between the suspended sediment concentration of tidal waters coming onto the marsh sites and sediment deposition on randomly distributed traps (b) and traps placed 1m from the water's edge (d). Regression lines in (a) and (c) are based on data from all ten sites. Regression lines in (b) and (d) are based on data from five fringing marshes or from five meadow marshes. Diamonds represent fringing marshes; open circles represent meadow marshes.

Data from the five randomly distributed traps at each site showed percent cover to be negatively correlated with the amount of sediment deposited (r=-0.433 all sites, r=-0.391 fringing marshes, r=-0.235 meadow marshes).

b) Traps randomly placed

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. 14). Areas where no marsh was present had an even greater mean amount of sediment deposited. However the variance around the mean was extremely high for 'no marsh' areas, with the standard deviation (6.838) greater than the mean (4.240 g/ m^2 /day). 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 (P=0.0006) covariate in the model (ANCOVA, P=0.3740, log transformed data). If elevation was not included in the model, then P=0.1340 (log transformed data). Sediment means for each site are presented in Appendix Table A7.

Because the two sites in Biddeford Pool (fringing marsh BPF and 'no marsh' area BPFX) had deposition rates so much greater than those observed at any other sites, the data were analyzed again after excluding these two sites. Figure 15 shows the mean amounts of sediment deposited at fringing, meadow and 'no marsh' sites. After excluding sites BPF and BPFX from the data analysis, there was still no significant difference observed between these three site types (P=0.1810, log transformed data).

c) Traps 1 m from edge

Traps placed just one meter in from the edge of the marsh sites collected more sediment than those that were distributed randomly. Once again there was no significant difference in the mean amount of sediment deposited on fringing, meadow and 'no marsh' sites, as determined by ANCOVA with elevation used as a covariate (P=0.1196, log

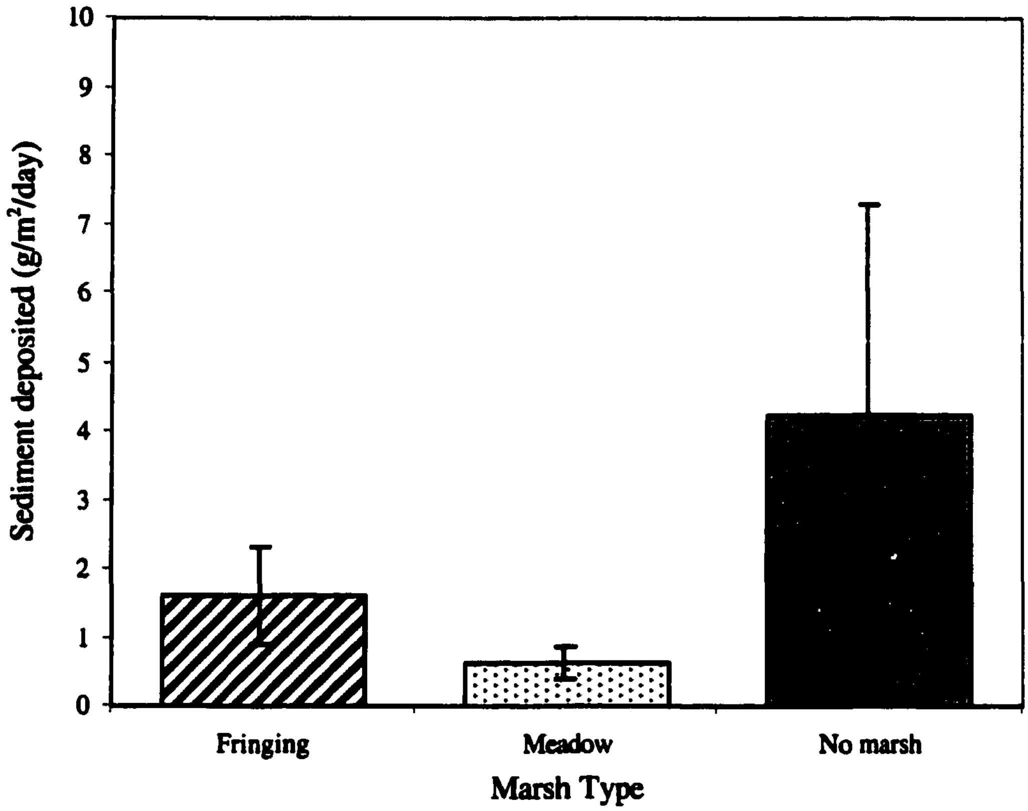


Figure 14. Amount of sediment deposited on fringing marshes, meadow marshes, and areas where no marsh was present. Traps were randomly distributed on each marsh. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the three means ($P = 0.3740$, log transformed data, elevation covariate $P = 0.0006$).

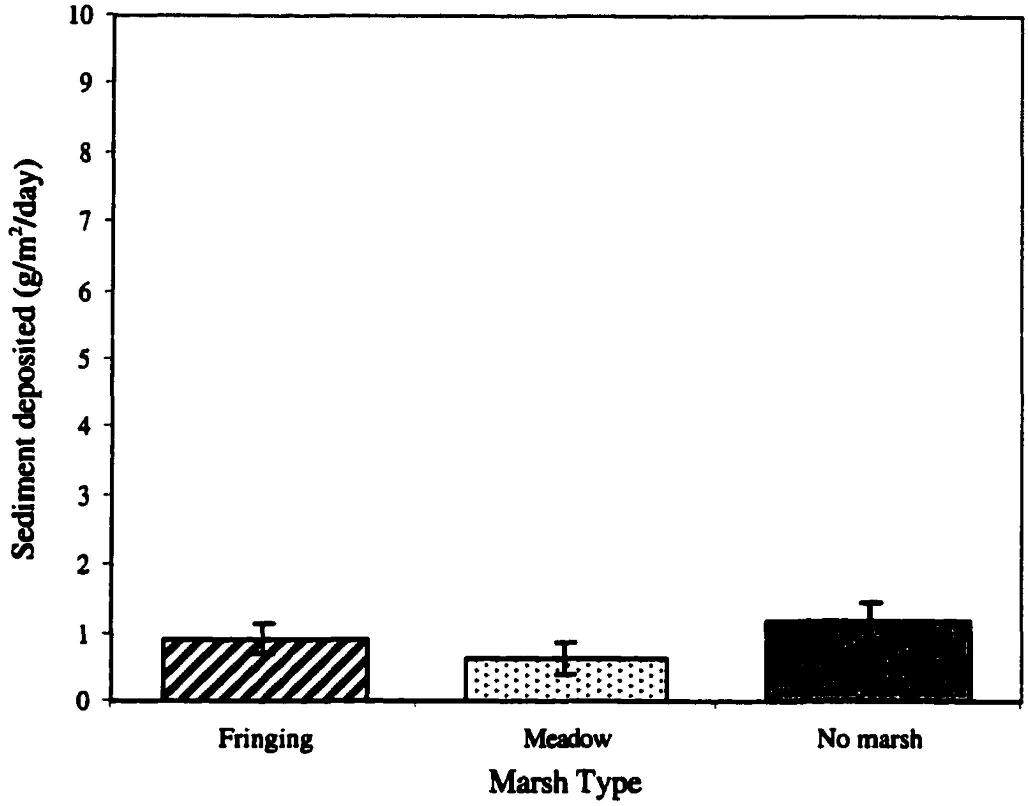


Figure 15. Amount of sediment deposited on fringing marshes, meadow marshes, and areas where no marsh was present, excluding sites BPF and BPFX. Traps were randomly distributed on each marsh. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the three means ($P = 0.1810$, log transformed data).

transformed data)(Fig. 16). If the variability due to elevation was not removed, P=0.7210 (log transformed data). When the two sites in Biddeford Pool (BPF and BPFX) were again removed from the data set and means recalculated, there was still no significant difference in the amount of sediment deposited on traps 1 m from the marsh edge in fringing, meadow or 'no marsh' sites (P=0.3461, log transformed data) (Fig. 17).

5. Dissipation of physical forces of waves

An example of the wave profiles generated from videotaping passing waves at 0 m and at 5 m can be seen in Figure 18. Along all transects at all sites, the heights of the largest waves at 0 m ranged from 3.5 cm to 27.3 cm, averaging 12 cm tall. The 'three wave mean' height (the mean height of three waves - maximum and two following - per take) at 0 m ranged from 2.7 cm to 21.2 cm, with an average of 7.8 cm.

It should be noted that 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, so waves were deep or intermediate water waves (Denny 1988).

a) Correlations with physical data

Several of the physical characteristics measured correlated with a site's ability to reduce the height of incoming waves. The water depth at 5 m and 7 m along the transects was negatively correlated with the percent wave height reduction (r = -0.421 for maximum waves, r = -0.464 for 'three wave mean'). The reduction in wave height was most highly correlated with the vegetation characteristics along the transects, such as the mean stem area/m^2 and the mean dry weight of plants at 0-5 m and 0-7 m. All correlation values are presented in Table 4.

b) Comparing fringing, meadow and 'no marsh' areas

As is evident in Figure 19, there was little difference in the ability of fringing and meadow marshes to reduce the height of the largest waves as they moved across the

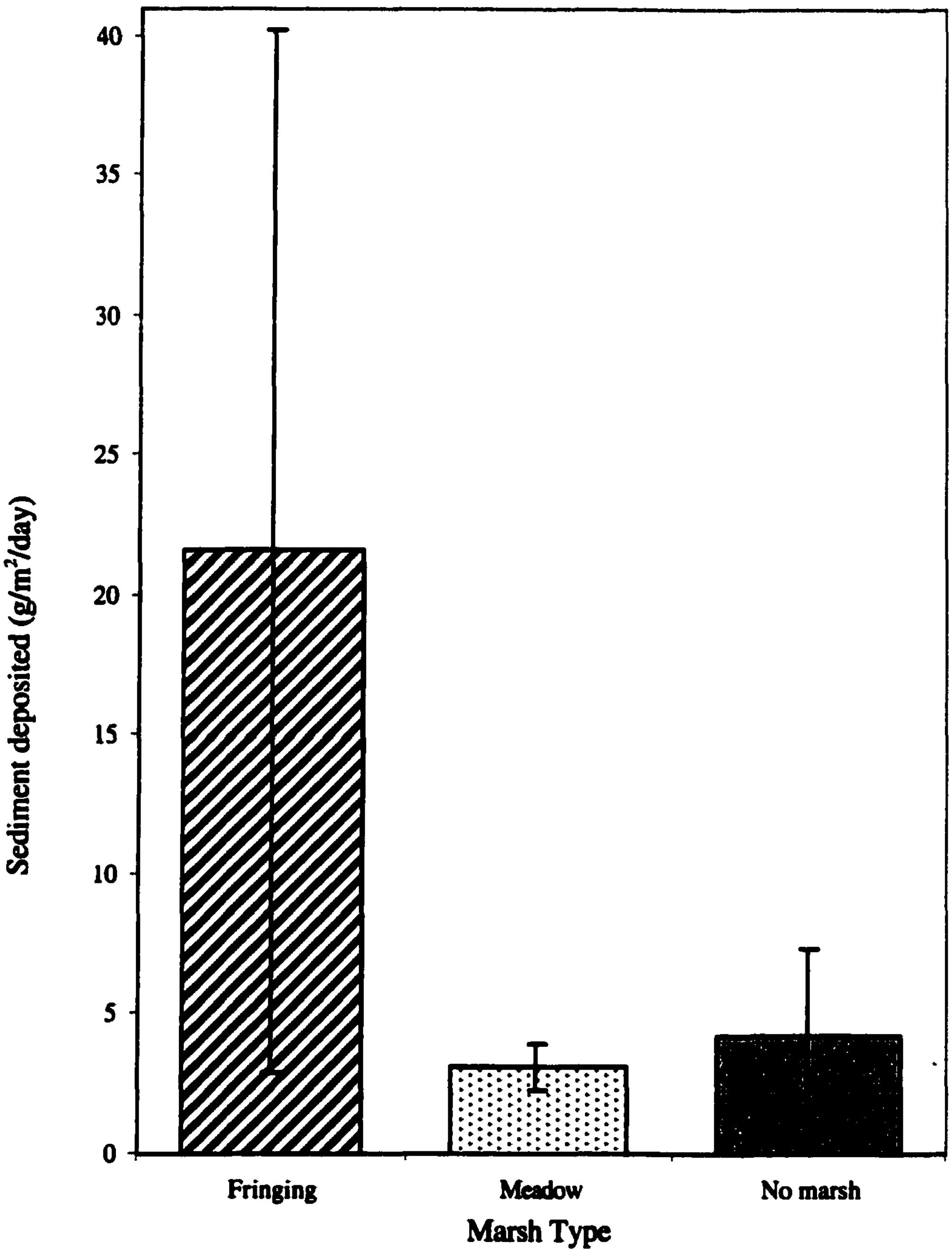


Figure 16. Amount of sediment deposited on fringing marshes, meadow marshes, and areas where no marsh was present. Traps on fringing and meadow marshes were placed 1m from the water's edge. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the three means ($P = 0.1196$, log transformed data, elevation covariate $P = 0.0340$).

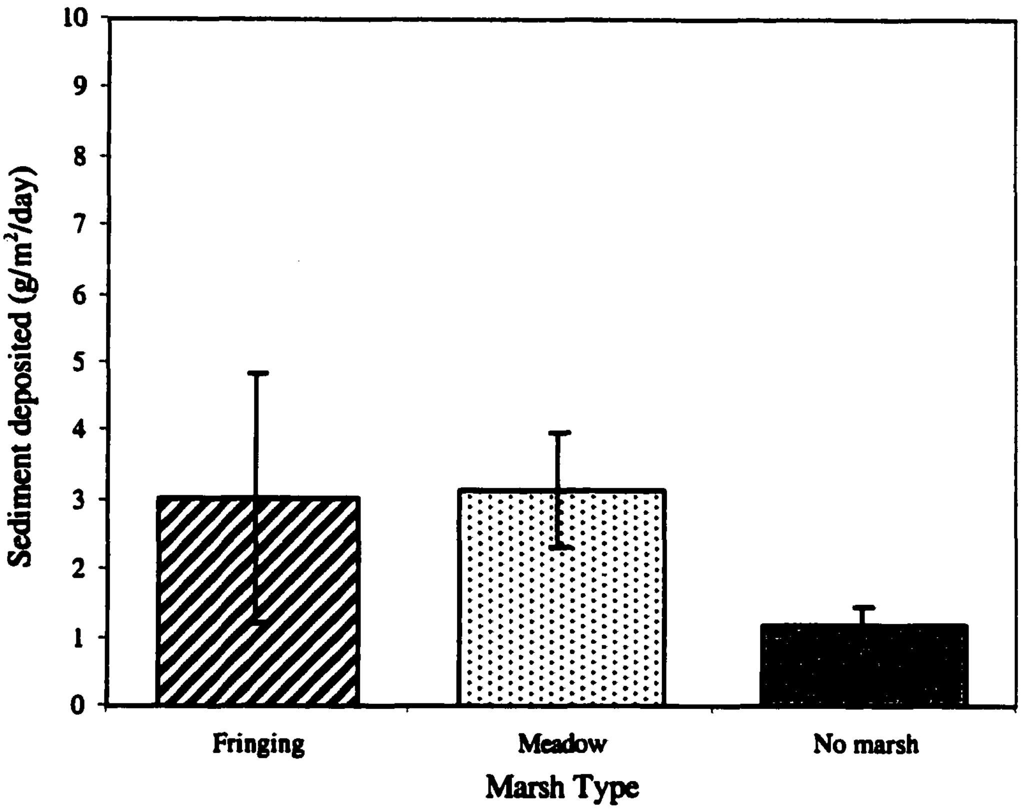
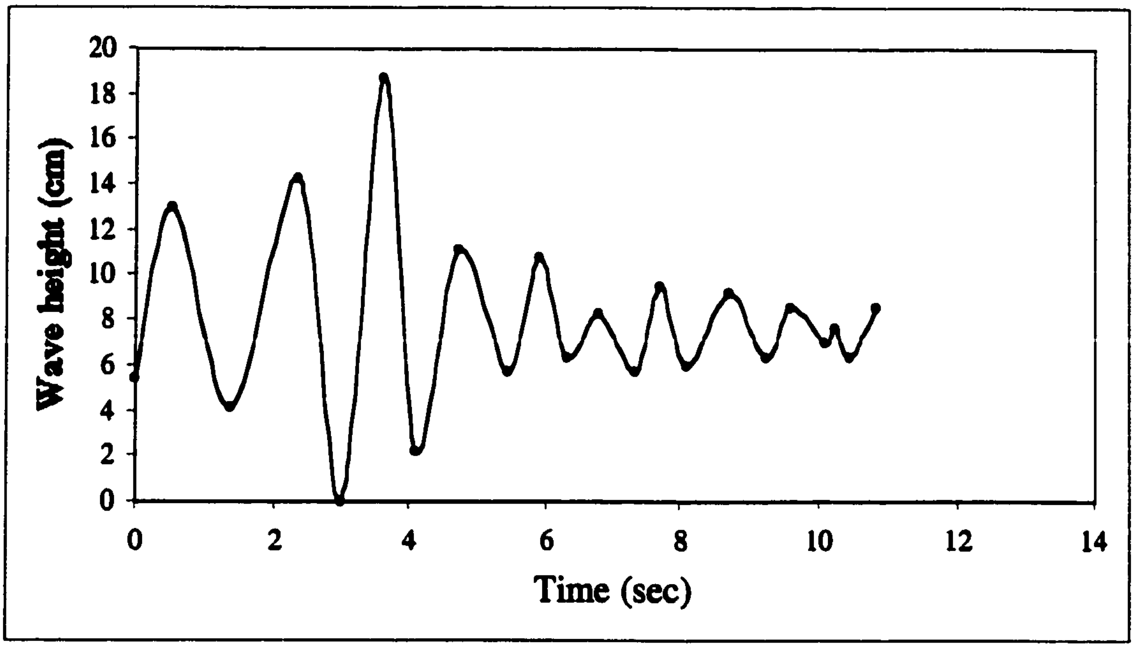


Figure 17. Amount of sediment deposited on fringing marshes, meadow marshes, and areas where no marsh was present (excluding sites BPF and BPFX). Traps on fringing and meadow marshes were placed 1m from the water's edge. Error bars are +/-1 standard error from the mean of five sites. There was no significant difference between the three means ($P = 0.3461$, log transformed data).



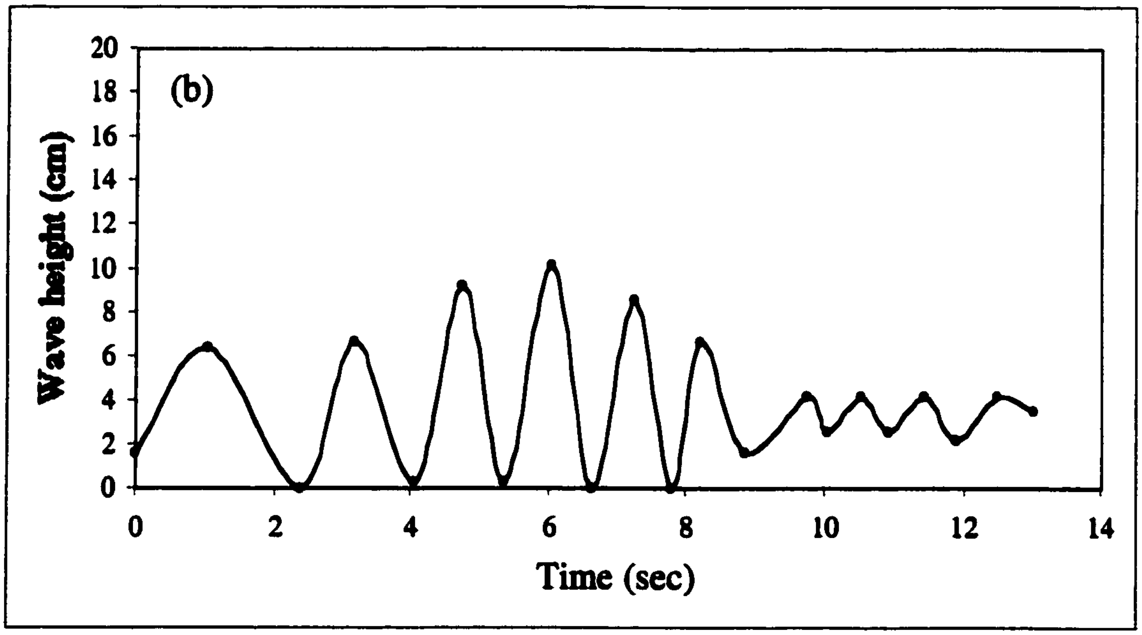


Figure 18. Wave profiles at MRM, a meadow marsh. Values for wave peaks and troughs were taken from videos simultaneously recording the passing waves at (a) 0m and (b) 5m along the transect.

Table 4. Correlations between the percent reduction in wave height and physical/biological characteristics along transects.

	Correlation coefficients (r)	
Physical characteristic	Maximum wave*	Three wave mean**
Percent surface slope	-0.017	0.098
No. stems/0.25m² (0-5m)	0.443	0.562
No. stems/0.25m² (0-7m)	0.455	0.611
Stem height (0-5m)	-0.060	0.061
Stem height (0-7m)	-0.071	-0.042
Stem diameter (0-5m)	-0.386	-0.381
Stem diameter (0-7m)	-0.490	-0.563
Stem area/0.25m² (0-5m)	0.433	0.555
Stem area/0.25m² (0-7m)	0.473	0.677
Dry weight of plants/0.25m² (0-5m)	0.534	0.633
Dry weight of plants/0.25m² (0-7m)	0.480	0.563
Water depth	-0.421	-0.464
Maximum wave height at 0m	-0.058	-0.123

* The percent reduction in height of the largest wave as it moved from 0m-5m or 0m-7m (indicated in parentheses following each physical characteristic).
** The percent reduction in mean height of the largest wave and the two waves following it as they moved from 0m-5m or 0m-7m.

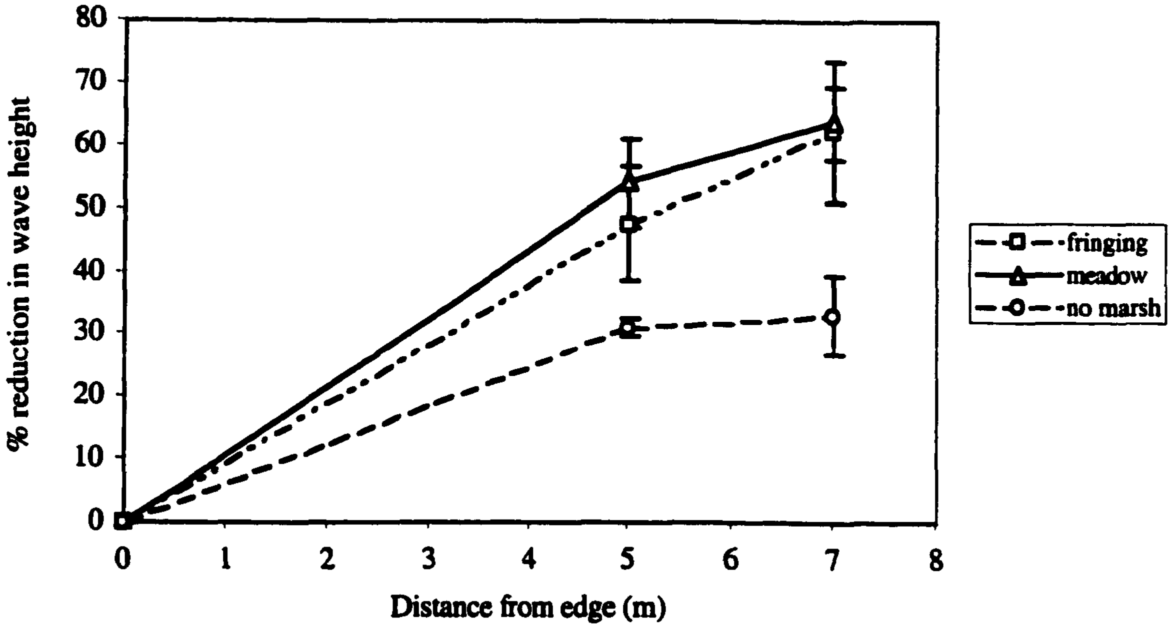


Figure 19. Percent reduction in maximum wave height in fringing, meadow and no marsh areas. Error bars are +/- 1 standard error from the mean.

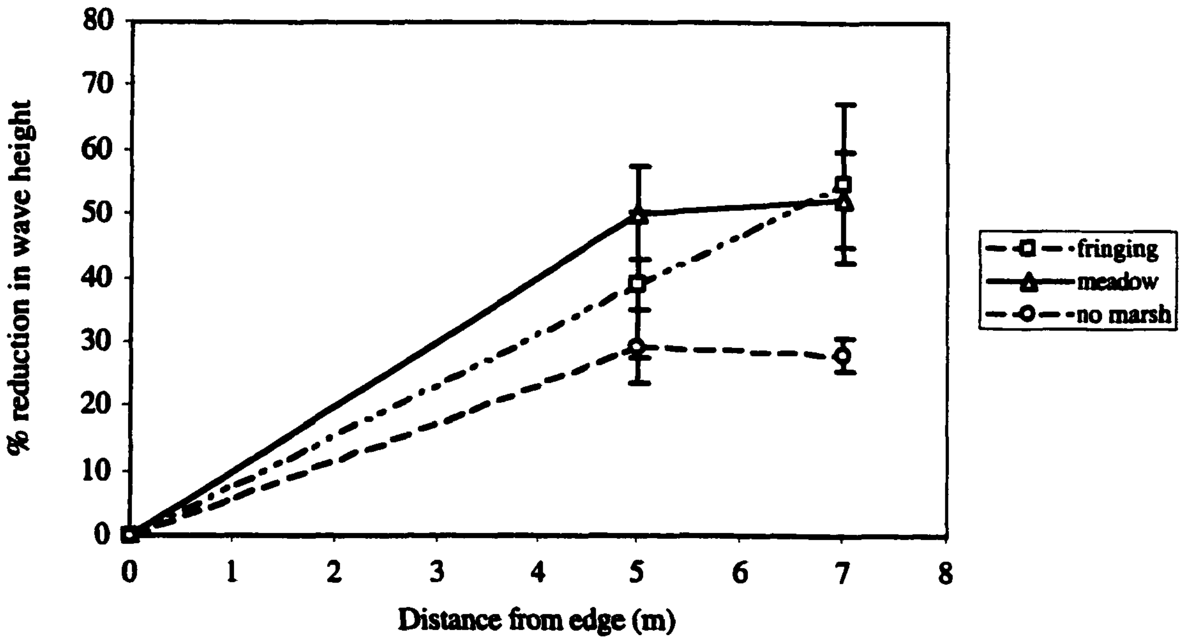


Figure 20. Percent reduction in 'three wave mean' height in fringing, meadow and no marsh areas. Error bars are +/- 1 standard error from the mean.

marsh surface. By the time they had traveled 7 m into the marsh, wave heights were reduced an average of 62% and 64% in fringing and meadow marshes, respectively. But, both fringing and meadow marshes were more effective at damping wave heights than were areas where no marsh was present. Where no marsh was present, wave heights were reduced by only 33%. This difference between marsh and 'no marsh' areas was statistically significant only at 7 m, however (ANOVA, $P=0.0488$, square root transformed data, Student-Neuman-Keuls test, $P<0.05$). ANOVA results showed no significant difference in the mean percent wave height reduction in fringing, meadow and 'no marsh' areas at 5 m ($P=0.0890$, square root transformed data).

The percent reduction in wave height was less when we considered the 'three wave mean' height (Fig. 20). Again there were no significant differences in the reduction in wave height after waves had traveled 5 m into fringing, meadow and 'no marsh' sites (ANOVA, $P=0.2966$). Although the 'three wave mean' height percent reduction was greater in the marsh sites (55% in fringing and 52% in meadow marshes) than in the 'no marsh' sites (28%) at 7 m, this difference was not significant (ANOVA $P=0.0548$, log transformed data). Wave data for the three transects at each site are included in Appendix Tables A8 and A9.

IV. Discussion

Much of the southern Maine/New Hampshire coast is lined with fringing salt marshes, and yet very little was known about them. To clarify their role(s) in the estuary, we studied how they function relative to the large meadow marshes found in the same areas. We discovered that fringing marshes are diverse in terms of their physical characteristics and that this diversity is sometimes reflected in their ecological functions. We also found that despite this diversity, in most cases fringing marshes as a group function at levels similar to what we observed in meadow marshes.

Previous studies have shown that the physical characteristics of salt marsh sites can influence some of their ecological functions (e.g. Gleason et al. 1979; Jacobson and Jacobson 1989; Knutson et al. 1982; Osgood and Zieman 1993; Warren and Niering 1993; Kastler and Wiberg 1996). We therefore measured several physical characteristics that might influence the functions we were investigating and looked for correlations between them. This allowed us to better understand the relationships, if any, between these physical characteristics and the marsh functions in which we were interested. Also, understanding these correlations allowed us to adjust for differences in important physical characteristics when testing the effects of marsh type on a particular function.

Comparison of fringing and meadow marsh functions

1. Primary production

No significant difference in mean peak-season standing crop was observed between fringing marsh sites and meadow marsh sites (Fig. 7). However there was a strong correlation between the mean percent surface slope and aboveground biomass in the fringing marshes (r=0.935), which were more steeply sloped than the meadow marshes (Fig. 6). 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. The "streamside effect" has been investigated by a number of researchers who observed that aboveground primary production is greater along the edge of marsh streams than it is further back on the marsh (Gallagher and Kibby 1981; Burdick et al. 1989). Soils in areas exposed more often to tidal waters are typically better 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).

The positive correlation we observed between the slope of fringing marshes and aboveground biomass is also similar to that observed by Steever et al. (1976) between tidal range and the standing crop production of *Spartina alterniflora*, where r= 0.963.

They concluded that tidal action contributed significantly to primary production, and their results supported the 'tidal energy subsidy' hypothesis first proposed by Odum and Fanning (1973). The mechanism of this 'tidal energy subsidy' to *S. alterniflora* production was later explained as an irrigation force that brings nutrients and oxygen to roots while flushing away waste materials (Odum 1980). Later research demonstrated that sediment oxygen levels were the primary factor controlling the aboveground production of *S. alterniflora* in a Massachusetts salt marsh (Howes et al. 1986). Additionally, the availability of oxygen has been shown in turn to influence nitrogen uptake rates by plant roots (Morris and Dacey 1984). Nutrients in salt marsh sediments become more available as tidal waters drain away and oxygen enters sediment pores (Howes et al. 1986).

The most steeply sloped fringing marsh had three times the aboveground biomass of the flattest fringing marsh. The high correlation between surface slope and aboveground biomass leads us to conclude that the more steeply sloped sites, which were flooded more often by the tides, were receiving a greater 'tidal subsidy.' This 'tidal subsidy,' coupled with good sediment drainage, likely resulted in more oxidized soils, greater nitrogen uptake rates, and higher aboveground production by the plants growing there.

The other physical factor that we expected to correlate with aboveground biomass was salinity. High soil salinity causes physiological stress to plants and may cause plant tissues to lose water to the surrounding hypertonic soil. Although many species have adapted to these conditions by developing strategies to prevent water loss, these strategies require an expenditure of energy by the plant (Teal 1986) which can result in reduced net primary productivity. Linthurst (1980) found that increasing soil salinity by 15 ppt resulted in a 42% reduction in biomass of *S. alterniflora*. Results of controlled experiments with *S. patens* have also shown a reduction in productivity with increasing salinity (Pezeshki and DeLaune 1993). The mean soil porewater salinity of the five meadow marsh sites was significantly greater than that of the fringing marsh sites we sampled (Fig. 5a), and most of the fringing marshes had lower porewater salinities than the meadow marshes. However we found no correlation between soil salinity and aboveground biomass at the quadrat level ($r=-0.076$ all sites, $r=-0.026$ fringing marshes, $r=-0.089$, meadow marshes).

Although 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), our values are in the same range as those found in studies of other Maine and New Hampshire salt marshes (Lindthurst and Reimold 1978; Gross et al. 1991). It should be noted that our method does not account for the turnover of new plant tissues during the growing season. Previous studies have shown that harvesting the peak season standing crop as a measure of aboveground production underestimates true aboveground net production by 10-15% (Nixon and Oviatt 1973).

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 4-7 times greater than that of aboveground production (Marinucci 1982). Our values for belowground biomass agree with what others have found in New England marshes (Lindthurst and Reimold 1978; Gross et al. 1991).

Although there was on average a greater amount of belowground biomass in meadow marshes than in fringing marshes, this difference was not statistically significant (Fig. 9). Some have hypothesized that in the high marsh, there is a greater allocation of biomass to underground reserves because interspecific competition among plants growing there is greater than between plants in the low marsh (Gross et al. 1991). Given that the proportion of high marsh to low marsh is much greater in meadow marshes than in fringing marshes, one might expect therefore to see greater amounts of belowground biomass per unit area in meadow marshes than in fringing marshes.

The high positive correlation (r=0.939) (Fig. 8a) we observed between belowground biomass and percent surface slope in fringing marshes may be caused by the same factors as those discussed above for aboveground biomass. Although differences in belowground biomass production in *Spartina* marshes have not been well studied, Gallagher and Kibby (1981) did find 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.

Our results demonstrate that the primary productivity of fringing marshes is as great as that of meadow marshes, indicating they are important contributors to estuarine food webs. Mean aboveground biomass in fringing marshes was almost equal to that in meadow marsh sites (Fig. 7), and although the mean belowground biomass in meadow marsh sites was 20% greater than that in fringing marsh sites, this difference was not significant (Fig. 9). When considering the salt marsh function of primary production in estuaries that contain both fringing and meadow marshes, such as those in New Hampshire and southern Maine, fringing marshes should not be overlooked. This is especially true in estuaries where fringing marshes predominate.

2. Soil organic matter accumulation

It should be acknowledged that a "one time" percent organic matter measurement is not necessarily an indicator of organic matter accumulation. For example, one site may have a higher percent organic matter content than a second site, but this may be due to a proportionally small rate of inorganic sediment deposition onto the marsh surface of the first site (compared to organic depostion). The second site may have a much lower percent soil organic matter value because inorganic sediment inputs to it were proportionally greater. Ideally, to assess the function of soil organic matter accumulation, one would monitor the amount of organic matter present over time. However given that the soil percent organic matter and the total amount of organic matter present in the top 15 cm of the marshes surveyed was so highly correlated (r=0.95), this "one time" measurement expressed as a percent can provide insight into the accumulation of organic matter that occurred at these fringing and meadow marsh sites.

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. Along the Gulf of Maine, sea level has been rising between 0.9 and 3.9 mm/yr., and there is evidence that along parts of Maine's coast, salt marshes are not keeping up with the rate of sea level rise (Kelly 1992). 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 (Redfield 1972; Nixon 1982).

The build up of organic matter in marsh soils appears to be most important in the high marsh zone. Schmitt et al. (1998) found an increase in the amount of organic matter deposited on the marsh surface and in the sediment with increasing elevation in a Massachusetts salt marsh. 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) also found that the decomposition rate of live roots and rhizomes was slower in the high marsh zone than at the marsh edge, which would lead to a greater accumulation of organic matter in high marsh soils.

Our results show that the percent organic matter content of meadow marsh soils is more than three times that of fringing marsh soils (Fig. 11). We also found a positive correlation between elevation and percent soil organic matter values (Fig. 12), which agrees with the findings of Schmitt et al. (1998). Because the mean elevation of the meadow marshes we studied was significantly greater than the mean elevation of the fringing marshes (Fig. 5b), one would expect the soil organic matter content of meadow marshes to be greater. However, when elevation was removed as an effect, the effect of marsh type was still significant, indicating that factors other than elevation also contribute to the difference we observed in percent soil organic matter between fringing and meadow marshes.

The distance 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 our study, the average distance from the edge of the marsh to the nine quadrats sampled on meadow marshes was greater than on fringing marsh quadrats (Fig. 5d), and the soil organic matter content did correlate with the distance from the edge of the marsh to the quadrats sampled at all sites ($r = 0.643$). Tidal waters contain suspended sediment that can be deposited on the marsh surface, contributing to the inorganic content of marsh soils. Marsh areas farther from the water's edge are covered by tidal waters for less time and so are not exposed to this sediment load for as much time as areas that are flooded more frequently. In addition, most of the sediment in waters coming onto the surface of a salt marsh is deposited close to the water's edge. Stumpf (1983) found that 80% of the suspended sediment load was deposited within the first 12 m of the creek edge in a Delaware salt marsh. Marsh soils farthest from the water's edge should therefore have proportionally a lower inorganic and a higher organic matter content than soils closer to the water's edge, and the results of our study support this.

It is difficult to sort out whether the greater organic matter content of meadow marsh soils is more influenced by the higher elevations of the meadow marsh sites compared to the fringing marsh sites, or to the fact that the quadrats sampled at meadow marsh sites were farther from the edge than the quadrats sampled at fringing marsh sites, because these two physical parameters are correlated with each other (r = 0.483).

Marsh age and ice scouring are two additional factors that could help explain the lower soil organic matter content in fringing marshes than in meadow marshes. Meadow marshes, which are probably older than fringing marshes, would have a longer time to accumulate soil organic matter, and would be more likely to contain peat 15 cm deep (the depth of the sampled cores). And finally, salt marshes in Maine and New Hampshire are subjected to ice scouring, which occurs most at the seaward edge of the marshes. Scouring by ice may remove a proportionally greater amount of peat from narrower fringing marshes than from wider meadow marshes.

In summary, the results of this study indicate that meadow marshes along the southern Maine/New Hampshire coast rely more on soil organic matter accumulation for accretion than fringing marshes do. We conclude that the salt marsh function of soil organic matter accumulation is performed to a greater extent in meadow marshes than in fringing marshes. 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 their predominant mechanism of accretion.

3. Maintenance of plant diversity

To compare plant diversity in fringing and meadow marshes, the first question we addressed was, "Do meadow marshes contain a greater number of species than fringing marshes?" To answer this question completely, one would have to do a census of all the plants growing at each site, a formidable task for any site of significant size. Second best would be to sample all sites using the same sampling intensity. Results of our earlier studies of fringing marshes informed us that a minimum sample size of ten quadrats per marsh site would be needed to adequately sample species richness at fringing marsh sites. We had determined this by sampling more than 60 random quadrats on several fringing marshes, and calculating running means of the number of species per site. To sample meadow marshes with the same sampling intensity, we would have had to sample over one hundred 1 m^2 quadrats at the larger meadow marsh sites. Because this was not practical, we decided to sample thirty 1 m^2 quadrats at meadow marsh sites, which at least would give a better representation of the species richness per site than if we sampled only ten quadrats at those sites. However because it is well known that as sample size increases, the number of species sampled also increases (Magurran 1988), we also calculated meadow marsh species richness based on only ten random quadrats per site, the same number used in fringing marshes. By holding the number of quadrats constant (at ten) we were able to remove the "area effect" when looking at species richness. This allowed us to explore factors other than sample size that might influence the differences in species richness we observed between meadow and fringing marshes.

Our results using the full sample of ten quadrats in fringing marshes and thirty quadrats in meadow marshes did show that meadow marshes had significantly greater species richness than fringing marshes at the whole site level. The much larger size of meadow marshes compared to fringing marshes certainly contributed to the differences we observed in species richness, but size does not appear to be the only factor influencing species diversity. The hypothesis that the size of a habitat is related to the number of species it supports was proposed by MacArthur and Wilson (1967), who studied the species richness of different sized tropical islands. The basic premise of their island biogeography hypothesis that species richness increases as the area of an island increases has also been observed in a variety of non-island habitat types (Cox 1993). Although MacArthur and Wilson (1967) showed that area alone accounted for *most* of the difference in species richness between large and small islands, they acknowledged that habitat area was correlated with environmental diversity. That is, larger habitats often have greater environmental diversity than smaller habitats, and this increase in habitat diversity likely contributes to the greater species richness of larger sites.

In our study of fringing and meadow salt marshes, sampling at a number of scales allowed us to observe correlations between species richness and a variety of the physical parameters (soil salinity, elevation and percent surface slope) that contribute to environmental diversity at these different scales. At the whole site level, species richness was greater in meadow marshes than in fringing marshes. Is this simply an area effect? Using the full sample of quadrats (10 FM and 30 MM), species richness was correlated with area ($r=0.818$), but it also correlated with slope ($r=-0.726$) and somewhat with elevation ($r=0.460$). When an equal sample size was used on both marsh types (10 FM and 10 MM), the area effect of our sampling protocol was removed, and although species richness was still greater on meadow marshes, this difference was no longer significant, although it became significant if elevation was included as a covariate. The positive relationship we observed between elevation and species richness could be due to differences in the degree of stress that salt marsh plants experience at different elevations. Plants experience less stress at higher elevations where flooding is decreased and soil oxygen content is greater. In addition, physical disturbances to the marsh surface and interspecific competition have been observed to increase diversity in the high marsh zone (Bertness and Ellison 1987).

Most interesting, however, are the results of the species density analysis. At this very small scale of 1 m^2, meadow marshes support a significantly greater number of species than fringing marshes. Species density correlated with both elevation ($r=0.792$) and percent surface slope ($r=-0.806$) at this scale.

Because elevation and percent surface slope are somewhat autocorrelated ($r=-0.614$), it is difficult to separate out the effects of these two environmental parameters. The steepest slopes were located in low marsh areas closest to the water's edge, and the flatter areas were in the high marsh, where elevations were greater. Low marsh areas in New England salt marshes are typically dominated by *Spartina alterniflora*, and the sites we studied fit this pattern. However the high marsh zones of most of the meadow marshes in our study did not completely fit the zonation pattern of the typical southern New England high marsh, which have distinct zones of *S. patens* and *J. gerardii* (Niering and Warren 1980). Although these high marsh species were the dominant plant species at most of our meadow marsh sites (Appendix Table A5), the sites also contained many patches of forbs, similar to those described by Miller and Egler (1950) in a Connecticut salt marsh. They discovered that high marsh plant communities dominated by forbs and stunted *S. alterniflora* develop in low areas of the high marsh, where soil Eh is lower, and salinity and sulfide levels are higher. This patchy distribution of forbs on the high marsh may account for the greater species richness we observed in the high marsh of meadow marsh sites, even at the quadrat level. Jacobson and Jacobson (1989) also found mosaic patterns of vegetation in a number of the Maine salt marshes they sampled, which they hypothesized was due to greater microrelief in high marsh areas.

Another possible explanation for the greater species richness observed in meadow marshes may be related to the relative age of the sites. Jacobson and Jacobson (1989), in their study of Maine tidal marshes, also found that small marshes (0.01-0.04 km^2 in area) had fewer species than larger marshes. However they attributed this not to differences in area but to the relatively young age (5-100 years old) and geological instability of the smaller marshes. If the fringing marshes we studied are younger than the meadow marshes, their high marsh zones may not have had the time necessary to develop more species rich plant communities.

Although meadow marshes have greater species richness, their plant communities are comparable to those of fringing marshes in terms of evenness (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.

Fringing marshes in this area have previously been described as having plant communities dominated by *S. alterniflora*, with limited high marsh development (Bryan et al. 1997; Cook 1993). The fringing marsh sites we sampled contained a good proportion of low marsh, dominated by *S. alterniflora* (20-46%) (Table A6). However, all of the fringing marsh sites we studied had well defined high marsh areas, and all sites included *S. patens* (Appendix Tables A5, A6). In two sites (YRF and BPF), there was more *S. patens* than *S. alterniflora*. So, although the proportion of high marsh to low marsh in fringing marshes (0.7:1) is less than in meadow marshes (3.4:1), high marsh species are an important component of fringing marsh plant communities.

To summarize; (1) the greater plant species richness observed in meadow marshes is not due solely to their larger size. Marsh surface slope and elevation are also correlated with species richness, at both the whole marsh scale and at the 1 m^2 scale. (2) The fringing marsh plant communities we studied did have a distinct high marsh zone. And although most of the sites we studied had proportionally more low marsh than high marsh, this was not always the case. (3) The relative abundances of plant species, as described by the evenness index E, were similar in fringing and meadow marshes.

4. 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 not find so appetizing. In one study of sediment deposition on Louisiana tidal marshes, Reed (1989) found rates of 2.9 g/m^2 /day (excluding winter storm events, when sedimentation rates were much higher). We obtained similar values for sediment deposition, with marsh site means ranging from 0.44-4.31 g/m^2 /day for traps randomly distributed on fringing marshes and 0.20-1.51 g/m^2 /day for traps randomly distributed on meadow marshes (Appendix Table A7).

We found that sediment deposition rates decreased with increasing elevation, probably because tidal waters cover marsh areas at higher elevations for a shorter period of time (Fig. 13a). In addition, as mentioned above, others have observed that the suspended sediment concentration of water moving onto the marsh surface drops rapidly in the first few meters after it enters the marsh due to marsh vegetation slowing tidal waters and trapping suspended sediment (Stumpf 1983). Negative correlations between elevation and sediment deposition have also been observed in Massachusetts (Schmitt et al. 1998) and North Carolina (Leonard 1997) salt marshes.

The negative correlation between plant percent cover and sediment deposition is not what we expected (Appendix Table A3), as Gleason (1979) found that the density of planted *S. alterniflora* had a positive influence on the amount of sediment deposited, with higher grass stem densities trapping greater amounts of sediment. However our percent cover estimates include all plant species present, even high marsh species. And percent cover was positively correlated with elevation ($r=0.56$), so the decrease we saw in sediment deposited in areas with greater percent cover could be a result of increasing elevation. Also, the plants themselves trap some sediment on their stems and leaves (Stumpf 1983). In high marsh areas with dense mats of *S. patens* covering the marsh surface, much of the sediment in the water column may not reach the disc, but may remain on the vegetation.

In addition to the sediment traps placed in fringing and meadow marsh sites, traps were placed in intertidal areas where no marsh vegetation was present (designated as 'no marsh' areas). This was to allow us to investigate whether the presence of a salt marsh was related to the amount of sediment deposited, or if other factors such as surface slope were more important.

Our expectation was that per unit area, more sediment would be deposited on marsh areas than on 'no marsh' areas, primarily because of the results of previous studies which related the presence and density of marsh vegetation to sediment deposition. We also expected greater sediment deposition per unit area on fringing marshes than on meadow marshes. This was because, considering the length of marsh bordering tidal waters, fringing marshes have a greater edge: area ratio than meadow marshes. As mentioned earlier, previous studies have shown that more sediment is deposited on the marsh surface near the water's edge than farther back into the marsh (Stumpf 1983; Reed 1988; Reed 1992; Leonard 1997). Our results showed that on average, the rate of sediment deposition was greatest on 'no marsh' areas, followed by fringing marsh sites and meadow marsh sites, but these differences were not significant (Fig. 14). This may be due to the high variability between sites within each site type, especially between 'no marsh' sites, where the mean amount of sediment deposited on each of the five sites ranged from 0.62-16.44 g/ m^2 /day (Appendix Table A7). Because Biddeford Pool appears to be an area of high sediment deposition, we reanalyzed the data after excluding BPF and BPFX from the data set. The cause of the large amount of sediment deposited on sites in Biddeford Pool is not clear, since we do not know the source of the sediment deposited on the traps. The sediment deposited could have come from the sites themselves, as reworked surface sediment, or from eroding marshes elsewhere in the Pool. Another possibility is that tidal or fresh waters entering the Pool could have contained large amounts of sediment. However eliminating sites in Biddeford Pool from the data analysis did not substantially alter the outcome; there was still no significant difference between site types (Fig. 15).

To eliminate the effect of the greater edge: area ratio of fringing marshes, we placed traps at fringing and meadow marsh sites just 1 m from the water's edge. The mean rate of sediment deposition was much greater near the water's edge than when traps were randomly distributed on the meadow and fringing marsh sites. But there was no difference in the rate of deposition (1 m from the water's edge) between fringing, meadow and 'no marsh' sites (Fig. 16). Again the two sites we studied in Biddeford Pool (BPF and BPFX) had very high deposition rates, which contributed to the high errors around the means for fringing and 'no marsh' sites. When we analyzed the data without these two sites, the variability was greatly reduced. Mean sediment deposition values for meadow and fringing marsh sites were greater than for areas where no marsh was present, although again there was no significant difference between these three site types (Fig. 17), indicating that marsh type does not influence the amount of sediment deposited at the marsh edge.

The rates of deposition and erosion of sediment at a salt marsh site will determine whether the site is drowning, expanding or being maintained over time (Phillips 1986). Factors contributing to deposition of sediments include the amount of sediment in waters flooding the marsh surface, the energy of the site (which is related to how protected it is from wind, waves and currents), and the amount of organic matter input from the site itself. Contributors to erosion are sea level rise, wide fetches and large waves, three factors that can reinforce each other. Finkelstein and Hardaway (1988) studied long-term sediment accumulation in fringing salt marshes along the York River, Virginia, and determined that these sites were eroding faster than they were accreting. They concluded that higher wave energies and sea level rise were primarily responsible for the loss of fringing marsh area. They also concluded that whether salt marshes erode or accrete is site specific. Fringing marshes, because they are located along the edges of rivers and bays, are exposed to a wide range of fetches and wave energies. For example, site LHF is exposed to greater wave energy than site ICCF, which is located along the edge of a small cove. The inorganic sediment input to fringing marshes is also quite variable, as our suspended sediment values indicate (Appendix Table A7). The variability in sediment input, fetch and the energy of the fringing marsh sites we studied is likely related to the variability we observed in the amount of sediment deposited at these sites, and ultimately to whether they will be maintained as sea level rises in the future.

After observing that meadow marsh soils have higher organic matter content than fringing marsh soils, we had concluded that fringing marshes must be relying more on inorganic sediment deposition to keep pace with sea level rise. However our sediment trap results do not clearly support this conclusion. Although our results suggest that fringing marshes trap greater amounts of sediment per unit area than meadow marshes (Figs. 14 and 15), the variability between sites was too high and our sample size of five fringing and five meadow marsh sites was too small to definitely support this conclusion. Whether fringing and meadow 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 needs further investigation.

It should also be noted that although original objective was to look at differences in sediment filtration and trapping at meadow marshes, fringing marshes and 'no marsh' areas, the sediment deposited on the traps we used included both resuspended and newly-deposited sediments. To get a better picture of the net amount of sediment deposited on marsh surfaces, techniques that measure longer-term accretion should accompany the shorter-term measurements made using sediment traps. Marker horizons such as feldspar or brick dust can be employed to estimate accretion rates over a time scale of less than a year (Cahoon and Turner 1989).

5. Dissipation of physical forces of waves

Previous studies have shown that salt marshes do 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 water velocity, resulting in increased sediment deposition on the marsh surface and decreased sediment erosion (Leonard and Luther 1995). As mentioned earlier, sediment deposition on the marsh surface is important if a marsh is to keep pace with rising sea level. We were interested in knowing if marsh type (fringing or meadow) affected a marsh's ability to reduce the height (energy) of incoming waves. We also studied the influence of a site's physical characteristics (vegetation, surface slope, and water depth) on its ability to dampen waves.

We observed vegetative cover to be an important factor in the reduction of wave heights as they traveled onto the marsh. The density of plant stems and the biomass of plants per unit area along transects both correlated positively with a decrease in wave heights (Table 4). Leonard and Luther (1995) found the total kinetic energy present in waters flooding dense *S. alterniflora* to be 2-3 times less than in adjacent open water areas. We found stem diameter to be negatively correlated with the reduction in wave energy; wave heights were reduced less in areas where stems were large than in areas where stems were small. However this is partly due to the fact that stems are widest when plant stem density is low. Stem width and stem density were negatively correlated along our 7 m transects (r=-0.713). When we calculated total stem area per unit area of marsh surface (stem density * stem diameter), we found this parameter to correlate positively with sediment deposition (r=0.473).

Waves lost less energy as they traveled along the transects when water depth was greater (Table 4), which agrees with the findings of Moeller et al. (1996) who studied wave energy loss in a *S. alterniflora* marsh and an adjacent sand flat. In addition, they found that water depth was more highly correlated with reduction in wave height across the salt marsh (r= -0.73) than across the sandflat (r=-0.46). At our sites, a similar relationship occurred, with the water depth/height reduction correlation greater in marsh sites (r=-0.359) than in areas where no marsh was present (r=-0.142).

Our results led us to conclude that marsh type did 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 (Figs. 19 and 20). The 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% five meters into a *S. alterniflora* marsh, and 65% ten meters in. Leonard and Luther (1995) found a 65% reduction in the turbulent energy of water coming onto the marsh after it had traveled just 3m 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 Moeller et al. (1996) study of a *S. alterniflora* marsh in England, they found that low marsh areas absorbed 2-3 times as much wave energy as adjacent sand flats. Wave height reduction in their study was 58% across salt marsh and only 14% across the sand flat (the distance waves traveled was approximately 190 m).

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 energies to the point that adjacent shorelines will not experience their erosive forces. Although fringing marshes are narrow, they are wide enough to have the same dampening effect on incoming waves as a meadow marsh. This is because most of a wave's energy is dissipated within the first 7 m as it travels onto a marsh surface, regardless of whether the marsh is a fringing or meadow marsh. As mentioned earlier, fringing marshes are located in parts of the estuary where wave energies tend to be higher than they are near meadow marshes. These higher wave energies are due to the presence of larger fetches, as well as to greater amounts of boat traffic typically associated with these parts of the estuary. These greater wave energies could contribute to increased shoreline erosion. However, the presence of fringing marshes in these areas helps mitigate the erosive effects of waves generated there. The role of fringing marshes as buffers against the erosive forces of waves is therefore of particular importance.

V. Significance of Results and Importance to Management of Coastal Resources

A. Fringing salt marshes defined

Although fringing salt marshes are extremely common in northern New England, they have not yet been specifically defined. They have been described as marshes that are found along the edges of bays and rivers and are relatively long and narrow in shape. We can now more clearly define fringing marshes as having steeper slopes, lower elevations and soils with less organic matter than those of larger marshes. In addition, their plant communities usually contain both low marsh and high marsh zones, although in more equal proportions than is seen in larger marshes, where the high marsh dominates.

B. Functions and values of fringing marshes in the estuary

Fringing marshes have important functions and values in the estuary that had not been studied prior to this project. They are as productive as meadow marshes, making valuable contributions to detrital and grazing food webs. Their ability to filter and trap sediments from the water column improves water quality and contributes to the accretion of marsh surfaces, which is important in helping them keep pace with sea level rise. By dampening the energy of incoming waves, they protect the adjacent shoreline from erosion. The fact that wave heights were reduced by 62% only 7 m into the marsh means that these long narrow marshes are important coastal buffers against the energy of the sea. This is especially important because fringing marshes are often the only buffer between the erosive forces of waves and valuable upland coastal property. And finally, we now know that although fringing marshes may not contain as many plant species as larger meadow marshes, the relative abundances of the species present are similar in both marsh types. Also, fringing marshes do contain distinct high marsh zones dominated by the same plant species that dominate the high marsh in meadow marshes. Fringing marshes are therefore important contributors to salt marsh plant biodiversity in the estuary.

C. Information for decision-making and monitoring of resources

Knowing what fringing marshes are and understanding more about the values they provide (described above) can help coastal resource managers make more informed decisions about their fate. The outcomes of allowing impacts to fringing marshes will be better understood (eg. increased upland erosion). The results of this study could also be helpful in ongoing efforts to evaluate and monitor salt marshes in Maine and New Hampshire. Results of this study will be distributed to the authors of *the Maine Citizens Guide to Evaluating, Restoring and Managing Tidal Marshes*, and *the Method for the Evaluation and Inventory of Vegetated Tidal Marshes in New Hampshire*, both manuals for citizens to use in inventorying and evaluating local salt marshes. Both manuals use a scoring system that is based on marsh functions and values.

D. Baseline data for comparisons to created/restored fringing marshes

There are numerous created and restored salt marshes in southern Maine and New Hampshire. In any study of their success, comparisons must be made to nearby natural salt marshes. Our results contribute to the existing knowledge of meadow marsh ecology. More important, they provide some of the first quantitative information specific to fringing marshes, whose ecological functions had not previously been studied. This baseline information could be compared to data collected at impacted, restored or created salt marshes in the ME/NH area.

In addition, there is currently an effort underway in the Gulf of Maine (sponsored by the Global Programme of Action Coalition for the Gulf of Maine) to identify impacted salt marshes in need of restoration. Plans are also being made to monitor sites that have been restored and to compare their functions to those of healthy salt marshes. All of this information will be included in a common database for the Gulf of Maine. The results of this study could contribute to this developing database.

E. Methods developed for this study

Finally, this study also tested several field sampling methods that could be used by others studying salt marshes in this area. For example, the method of trapping sediments using Mylar discs is now being used by researchers at the University of New Hampshire and at the Wells National Estuarine Research Reserve. In addition, other researchers who want to compare elevations between sites could use our method for tying the elevations of all ten sites together in reference to a common point, high tide.

Our method for measuring wave dissipation was a synthesis of techniques used by Knutson (1982) and Moeller et al. (1997). Knutson (1982) also generated waves using a boat and measured wave energy along transects. However he used capacitance-type gages to measure waves and data were collected on a battery operated strip chart. We recorded wave heights with video cameras as the waves moved past stationary meter sticks. This technique was employed by Moeller et al. (1997) to check wave measurement data they had collected using pressure transducers mounted 5-10 cm above the sediment surface. Although viewing the wave videos was a time-intensive effort, the hand-held cameras we used to record wave heights may be more accessible to some researchers than pressure tránsducers or capacitance-type gages.

VI. Summary/Conclusions

Our results indicate several important differences in the physical characteristics of the fringing and meadow marsh sites we studied, and suggest relationships between several of these characteristics and marsh functions. The percent surface slope was greater in fringing marshes than in meadow marshes. The variation in the slope of fringing marshes was related to aboveground biomass production, with greater productivity occurring on more steeply sloped marshes. There were significant differences in elevation between the two marsh types, with the five meadow marshes having a greater mean elevation than the five fringing marshes, and elevation was positively correlated with the soil organic matter of the marsh sites. Although fringing marshes had statistically lower mean soil salinity than the meadow marshes, this difference was primarily due to the very low soil salinity at one fringing marsh site. We found no strong correlations between salinity and any of the functions we studied. The fact that meadow marshes were so much larger than fringing marshes was in part the cause for the greater number of plant species found on meadow marsh sites, although surface elevation and percent slope were also correlated with plant species richness. The relative abundances of plant species were similar in fringing and meadow marsh sites.

Meadow marshes had significantly greater soil organic matter content than FMs (12.2% FMs, 42.0% MMs), but we saw no statistical difference between fringing and meadow marshes in their levels of primary production, sediment deposition or wave dampening. The mean aboveground, belowground and total biomass values for FMs and MMs were similar. Although our results suggest that FMs trap more sediment per unit area than MMs, this difference was not significant, probably due to the great variability among sites. However both site types trapped more sediment close to the marsh edge than further back into the marsh, as expected. Traps located 1 m from the edge trapped an average of 21.6 ±18.6 g/m^2/day (FMs) and 3.2 ±0.8 g/m^2/day (MMs), and traps randomly distributed on the marsh surface trapped an average of 1.6 ±0.7 g/m^2/day (FMs) and 0.6 ±0.2 g/m^2/day (MMs). When we investigated a site's ability to reduce the height of waves coming onto the marsh surface, we found that maximum wave heights were reduced by approximately 63% after traveling only 7 m in both marsh types. Of the characteristics we measured, the density and amount of vegetative cover were most highly correlated with reduction in wave height.

Although our knowledge of the role of fringing marshes has improved, the extent of the contribution they make to the estuary cannot be determined until we have an accurate picture of their total acreage. As Jacobson et al. (1987) pointed out, the number of small salt marshes far exceeds that of large marshes in Maine. In area, marshes smaller than the mean size for the state (0.026 km^2) comprise more than 40% of the total salt marsh acres. However, salt marshes smaller than 150 m^2 were not included in their study, so the authors recognized that theirs is a conservative estimate. As long as the sum total contribution of fringing marshes remains obscure they will not be adequately valued or protected (Table 1).

In addition, many of their functions have yet to be studied (Table 1). For example, because fringing marshes are often found along developed shorelines, they may be important in removing nutrients and contaminants from waters entering the estuary. This function has yet to be investigated. And although we now have some information about the sediment trapping ability of fringing marshes, we do not know if they are accreting fast enough to keep pace with sea level rise. Fringing marshes are often the only buffer existing between developed shorelines and the erosive action of waves, so their ability to accrete fast enough to maintain adequate elevations relative to sea level is very important and deserves further study.

CHAPTER III

TESTING THE INFLUENCE OF MARSH SURFACE SLOPE AND NORTH-SOUTH ORIENTATION ON THE GROWTH OF *Spartina alterniflora*

I. Introduction

Both the restoration and the creation of salt marsh habitat are presently occurring throughout New England, often to mitigate for unavoidable impacts to salt marshes in the area (Shisler 1990; Short et al. 2000). The construction of coastal marshes along the Atlantic and Gulf coasts of the United States dates back to the 1970s, when the U.S. Army Corps of Engineers created salt marshes by planting *Spartina alterniflora* on dredged material in an effort to stabilize eroding shorelines (Race and Christie 1982). A variety of techniques for establishing vegetation on newly constructed marshes have been attempted over the years, including seeding, planting greenhouse-grown seedlings, and transplanting field-harvested *S. alterniflora* plants (Broome et al. 1988). Through trial and error, methods have been developed that are likely to result in the establishment of *S. alterniflora* on the surface of newly constructed marshes. These methods, as summarized by Matthews and Minello (1994), are as follows: (1) young healthy plants should be used and should be obtained from as close to the planting area as possible, (2) planting should be conducted early in the growing season to provide adequate time for establishment, (3) the soil must contain adequate nutrients, (4) proper elevation (0.2-0.5 m above Mean Low Water) at the site is critical, (5) a gentle slope of 1-10% grade provides sufficient width and drainage for the marsh to develop, (6) protection from waves is particularly important for new plantings (the fetch should be less than 2 km), (7) protection of the new plants from pests such as herbivorous fish, insects, small mammals and man is often needed, and (8) protection from activities on adjacent lands has become increasingly important as coastal development continues.

Although the design of new salt marshes and methods for their construction have improved greatly over the years, questions still remain about how effective these marshes will be at replacing the functions and values of impacted salt marshes in the long term (Race and Fonseca 1986; Short et al. 2000). Just because a marsh is covered with *S. alterniflora* and looks like a salt marsh from a distance, one cannot assume that it is functioning as a healthy ecosystem, or that it is equivalent to a natural salt marsh (Broome et al. 1986; NRC 1992). However, current wetland policy in the United States allows for marsh construction as a way to compensate for the loss of wetland areas, and this policy is unlikely to change in the near future (Berry and Dennison 1993). So scientists and resource managers continue to try to improve existing wetland construction methods.

Along the Atlantic coast, recently constructed marshes face a number of physical stresses which can cause newly planted cordgrass to be uprooted and constructed marsh soils to erode. Waves generated by wind and boat traffic can cause erosion, and Canada geese have been observed to feed on underground rhizomes of young plants (Garbisch and Garbisch 1994). In addition to these stresses, constructed marshes in New England are exposed to freezing winter temperatures that can cause ice to form on their surfaces. In addition, ice floes often move across and gouge their surfaces. On natural salt marshes in the area, the break up in the spring of these large pieces of ice can rip up established marsh plants and scour away marsh soil (Bertness 1992). The detrimental impacts of ice are even more severe for young constructed marshes, where plants are not yet firmly rooted and where loose soils are more susceptible to erosion (Shisler and Charette 1984; Burdick et al. 1996). In addition, most of the constructed salt marshes in New England are smaller in size than those further south (Shisler 1990), and due to their relatively large length to width ratios, they are more susceptible to the erosive forces of wind, waves and ice than are larger constructed salt marshes.

The development of vegetation on constructed marshes can help to stabilize sediments and slow erosion, as *S. alterniflora* has been shown to dampen wave energies and trap sediments in waters moving across the marsh surface (Knutson et al. 1982; Shisler and Charette 1984; Broome et al. 1988; Leonard and Luther 1995; Moeller et al. 1996). Results from my study of fringing salt marshes showed wave dampening to occur to a greater degree in areas where marsh was present than where it was not (see Chapter 2). In addition, once transplanted cordgrass has developed sufficient aboveground and belowground biomass, Canada geese no longer pose a serious threat to the plants, as geese will not land in tall vegetation and rarely feed on plant rhizomes once a thick root mat has developed (Shisler 1990; Garbisch and Garbisch 1994). The early establishment of healthy *S. alterniflora* can therefore make an important contribution to the success of a constructed site (Shisler 1990).

The correct surface slope is an important criterion in the design and construction of created salt marshes. The slope should be steep enough to allow for proper soil drainage but not so steep that erosion becomes a problem (Bosworth and Short 1993; Matthews and Minello 1994). Garbisch and Garbisch (1994) recommend a surface slope of 10:1 for constructed marshes, although the slope may be less in certain circumstances. This agrees with Matthews and Minello's (1994) report of a desired slope of 1-10%.

My observations of the variability in growth among *S. alterniflora* plants in the natural and constructed marshes in the Great Bay Estuary led me to ask if marsh surface slope might affect the growth of transplanted cordgrass. I was also interested in investigating whether the north-south orientation of constructed sites affects plant growth, since planting recommendations call for newly planted sites to be exposed to direct sunlight for at least six hours per day (Garbisch and Garbisch 1994). The objective of this study was therefore to determine if surface slope and north-south orientation affect the growth of newly planted *S. alterniflora*. My hypotheses were (1) that the growth of newly-planted *S. alterniflora* would be greater on steeper slopes than on shallower slopes during the first growth season after transplanting, and (2) that the growth of newly-planted *S. alterniflora* would be greater on south-facing slopes than on north-facing slopes during the first growth season after transplanting.

II. Materials and Methods

A. Survey of created and natural fringing marsh sites

Before setting up the slope-orientation experiment, a number of sites were surveyed to determine the range of slope and orientation values among existing natural and constructed fringing salt marshes. I measured the north-south orientations and the surface slopes of six constructed and 26 natural fringing salt marshes in the Great Bay Estuary. The predominant orientation in a north-south direction was determined by taking a compass reading while facing open water, with the upland behind one's back. Values were then converted to a linear north-south scale, from 0° (north) - 180° (south), by subtracting readings greater than 180° from 360°. Surface slopes were measured along three equally spaced transects running perpendicular to the upland edge of the marsh. All slopes were measured using a water level attached to a hose, and a 50 m tape. An average of these three values was then calculated.

I found that 63% of the natural fringing marshes and 67% of the constructed marshes faced north. The natural marshes and constructed marshes had similar mean surface slopes: 10.4+/- 5.3% for natural sites and 13.8+/-11.9% for constructed sites. The range of slope values for natural sites was 3.8-25.1%, and for constructed sites the range was 1-33.5%. Based on these data, I selected slopes at the experimental marsh site of 3%, 10% and 25%.

I also collected end-of-season standing aboveground biomass from eleven of the 26 natural salt marshes I surveyed in the Great Bay Estuary. All vascular plant vegetation was clipped in six randomly distributed 0.5 m^2 quadrats, after which live plants were separated from dead material and dried at 60°C for 48 hr.

B. Experiments involving slope and orientation

1. Site description

The experiment was conducted along the seaward edge of a salt marsh in Biddeford Pool, Maine (43°27'16"N, 70°22'26"W), which is located approximately 50 km north of the Great Bay Estuary. This part of the marsh consisted of several finger-like projections, which provided both north-facing and south-facing slopes. The marsh vegetation in this area was almost exclusively *S. alterniflora*, which is flooded twice a day (MHHW=3.6 m).

2. Experimental Design

The experimental design was a two factor Analysis of Variance (ANOVA) with equal replication. Treatments were surface slope (with levels 3%, 10% and 25%) and orientation (with levels north-facing and south-facing). There were a total of n = 5 replicates for each slope/orientation combination, so there were a total of N = 30 observations in the experiment (Table 5).

Late in the spring (May 28), when *S. alterniflora* plants were large enough to be transplanted, 100 young plants were collected from the base of a shallow tidal creek adjacent to the experimental site. Roots and rhizomes were washed in seawater, and the leaf widths, leaf lengths, shoot height (the distance from the soil surface to the growing shoot tip), and rhizome length of each plant were measured. In addition, the number of leaves on each plant was counted. Sixty of these plants were then potted into black plastic pots (two plants per 3-liter pot). The top of each pot was covered with a dark gray landscape fabric (Typar Landscape Fabric, spunbonded polypropylene), in which two small holes were cut for the young plants. The soil was obtained from Blue Rock Industries in Westbrook, ME, and was similar to that used in marsh construction projects

Table 5. Experimental design for slope-orientation experiment, n = 5.

	3% slope	10% slope	25% slope
North			
South			

in this area. It was a mixture of fine sand (80%) and clay (20%), and its organic matter content was determined through loss on ignition to be 0.28%.

The other forty plants were divided into aboveground and belowground sections, dried at 60°C and weighed. The relationships between the plants' dry weights and the measured characteristics were determined by multiple regression.[2] These equations were then used to calculate the initial biomass of plants used in the experiment.

The thirty pots, each containing two young plants, were buried at the experimental site so that they faced either south or north, and were at a slope of 3%, 10% or 25%. Pots were buried so that the level of the soil in them was flush with the surface of the marsh. All the existing plants in a 0.5 m^2 area around each pot were clipped to prevent shading of the young plants in the pots. After one month, some shoots had died, so the least healthy extra shoot was removed from any pots with two shoots remaining, leaving one plant per pot for the duration of the experiment. The elevations of the soil levels in the 30 pots were measured using standard survey equipment, so that elevation could be included as a covariate in the data analysis. Elevations were calculated relative to the pot at the lowest elevation, which was assigned a relative elevation of zero.

Approximately every three weeks throughout the summer, the number of live and dead leaves per plant was counted, and the leaf lengths and shoot heights were measured. The plants in a 0.5 m^2 area around each pot were clipped as needed to prevent shading. In addition, the temperature of the soil in each pot and the soil adjacent to each pot (7 cm depth) was recorded at low tide on August 5.

At the end of the summer (86 days after planting), *S. alterniflora* plants were harvested and the characteristics measured at the beginning of the experiment were

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[2] Equations used to estimate initial dry weight values for plants are as follows:
Aboveground biomass = -0.195 + [0.051*(Total number leaves)] + [0.035*(Mean leaf length x width)] (r^2=0.698); Belowground biomass = -0.583 + [1.103*(Mean leaf length x width)] + [0.01*(rhizome length)] (r^2=0.638); Total biomass = -0.799 + [1.92*(Mean leaf length x width)] + [0.01*(rhizome length)] (r^2=0.707).

measured again. In addition, the above and belowground parts of each plant were dried at 60°C and weighed.

3. Data analysis

The initial and final total leaf areas per plant were calculated as (mean leaf length) x (mean leaf width) x (number of live leaves/plant). Differences between the final measurements (at 86 days) and the initial measurements were calculated for all characteristics for each of the 26 plants that survived for the entire experiment. The effect of slope or orientation on plant growth (for each characteristic) was then determined by two way ANOVA, with elevation as a covariate. Correlations between elevation and the characteristics measured were also calculated.

The average values for plant height, leaf length and number of live and dead leaves were also plotted over time for plants facing north and south, and for plants growing at the three different slopes.

III. Results

A scatterplot of the results of the survey of natural fringing marshes in the Great Bay Estuary demonstrated no strong relationship between surface slope and the end-of-season aboveground biomass in these eleven sites (Figure 21).

To determine if surface slope or north-south orientation had an effect on the growth of newly transplanted shoots, the mean difference between initial and final measurement for each growth characteristic was calculated and compared using two factor ANOVA. The values for the four plants that died over the course of the experiment were omitted from the data set. Neither slope nor orientation had a significant effect on plant growth for any of the growth characteristics measured. In addition, the slope x orientation interaction term was not significant in any case, indicating that the two treatments were independent of each other. Elevation was

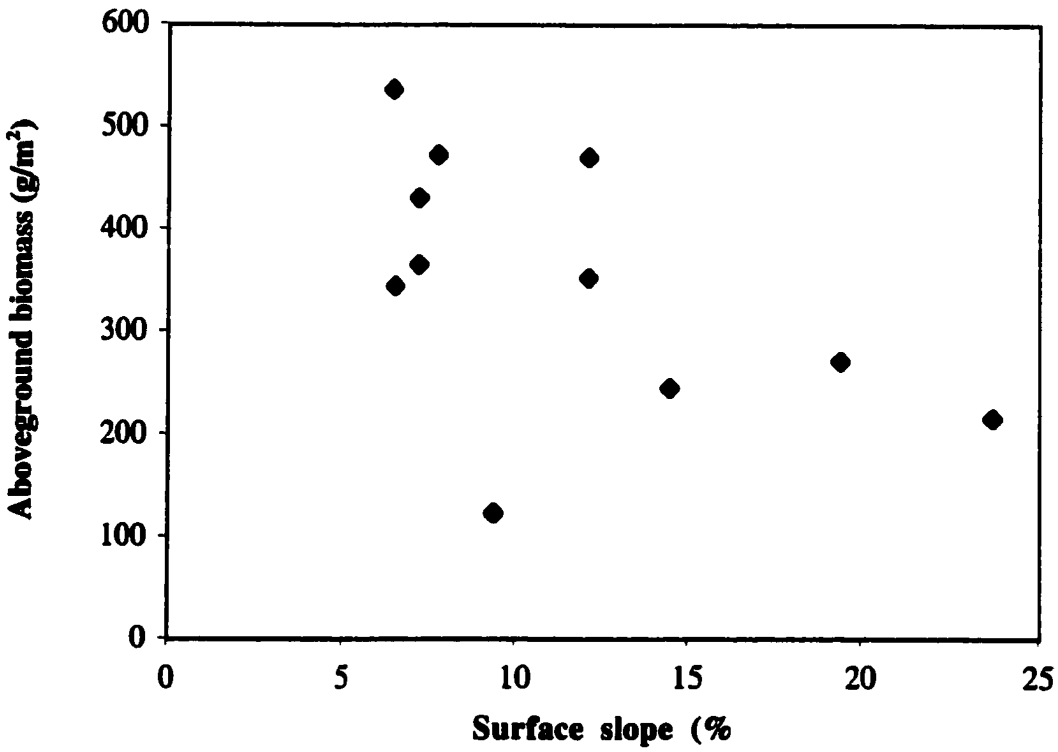

Figure 21. Correlation between surface slope and end-of-season standing aboveground biomass on eleven natural salt marshes in the Great Bay Estuary (r=-0.529).

included in the models as a covariate at first, but because it was not significant in any case, it was removed. ANOVA results are summarized in Table 6.

The elevations of all transplants were within a range of 21 inches (53 cm). Correlation analysis was also conducted to explore possible relationships between the elevations of plants and their growth. Calculated correlation coefficients were less than 0.125 for all growth characteristics except for the number of live leaves, which was slightly correlated with elevation ($r=0.368$).

The soil temperatures both inside and next to the pots on Aug 25 ranged from 22-26°C. Inside the pots, the mean soil temperature was 24.2°C +/- 0.2 SE, and outside the pots the mean soil temperature was 23.8°C +/- 0.2 SE. A two-way ANOVA showed no significant difference in the soil temperatures between pots at the three slopes ($p = 0.197$), or between pots facing north versus south ($p = 0.628$). There was also no significant interaction between slope and orientation ($p = 0.225$).

Figure 22 illustrates the relationship between north-south orientation and plant growth as measured by change in total leaf area, number of live leaves, rhizome length, aboveground and belowground dry weight, and total dry weight. The effect of surface slope on these same growth characteristics is shown in Figure 23. Initial measurements of transplanted *S. alterniflora* were very similar in all experimental groups. Growth did occur in all treatment groups for all of the characteristics measured, with the exception of rhizome length. The average rhizome length of plants growing at a 25% slope actually decreased from the original value (Fig. 23c). The mean rhizome length of north-facing plants also decreased slightly (Fig. 22c).

The rate of plant growth at different slopes and orientations was explored using plant measurement data collected approximately every twenty days throughout the course of the growing season. Figure 24 shows how the growth rates of north-facing and south-

Table 6. Summary of two factor ANOVA results. Treatments were surface slope and north-south orientation.

Dependent Variable (t_f-t_0)	df	SS	F	*P*
Total leaf area				
Slope	2	1360.448	1.344	.2833
Orientation	1	6.493	.013	.9109
Slope x Orientation	2	480.469	.475	.6289
Total	20	10121.477		
Number live leaves				
Slope	2	2.424	.225	.8005
Orientation	1	6.216	1.154	.2955
Slope x Orientation	2	9.750	.905	.4205
Total	20	107.750		
Rhizome length				
Slope	2	77.174	.777	.4738
Orientation	1	53.761	1.083	.3111
Slope x Orientation	2	5.209	.052	.9490
Total	20	943.373		
Aboveground biomass				
Slope	2	.072	.182	.8350
Orientation	1	.019	.094	.7618
Slope x Orientation	2	.008	.021	.9790
Total	20	3.969		
Belowground biomass				
Slope	2	.074	.054	.9472
Orientation	1	.025	.036	.8516
Slope x Orientation	2	1.280	.935	.4090
Total	20	13.692		
Total dry weight				
Slope	2	.136	.045	.9560
Orientation	1	.002	.001	.9729
Slope x Orientation	2	1.178	.389	.6827
Total	20	30.277		

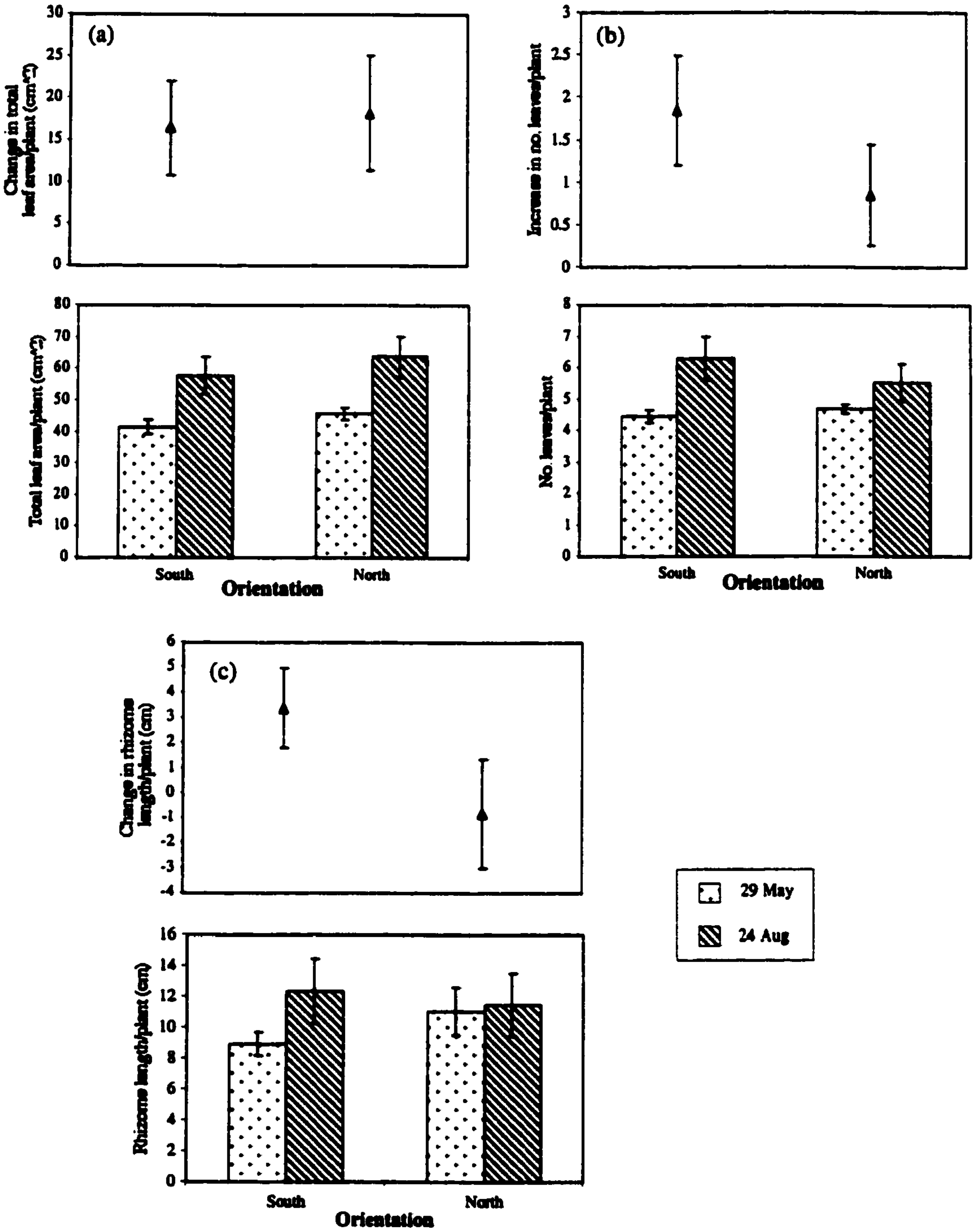

Figure 22a-c. The relationship between north-south orientation and plant growth as measured by change in (a) leaf area, (b) number of live leaves and (c) rhizome length. Error bars are +/-1 SE.

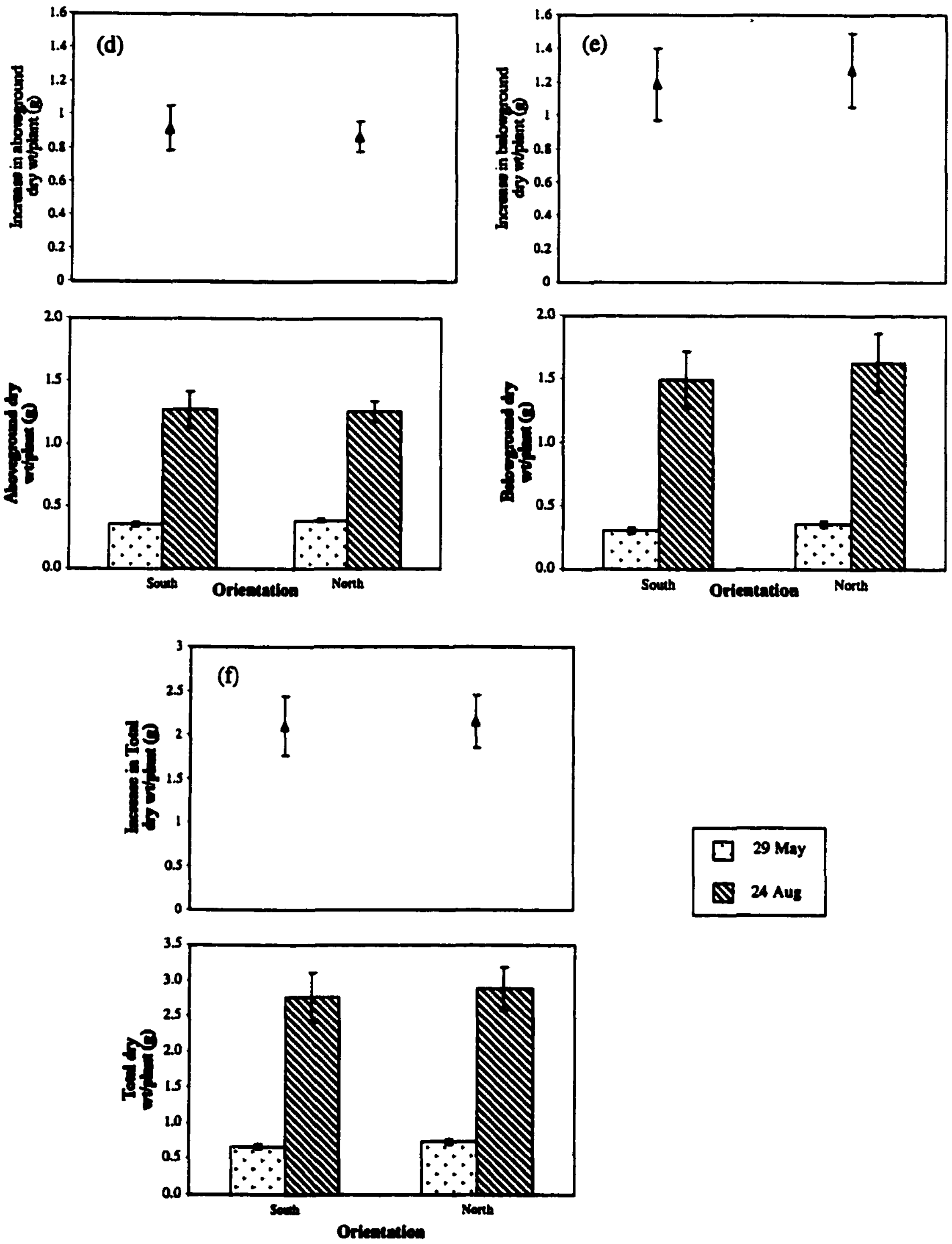

Figure 22d-f. The relationship between north-south orientation and plant growth as measured by change in (d) aboveground dry weight, (e) belowground dry weight and (f) total dry weight. Error bars are +/-1 SE.

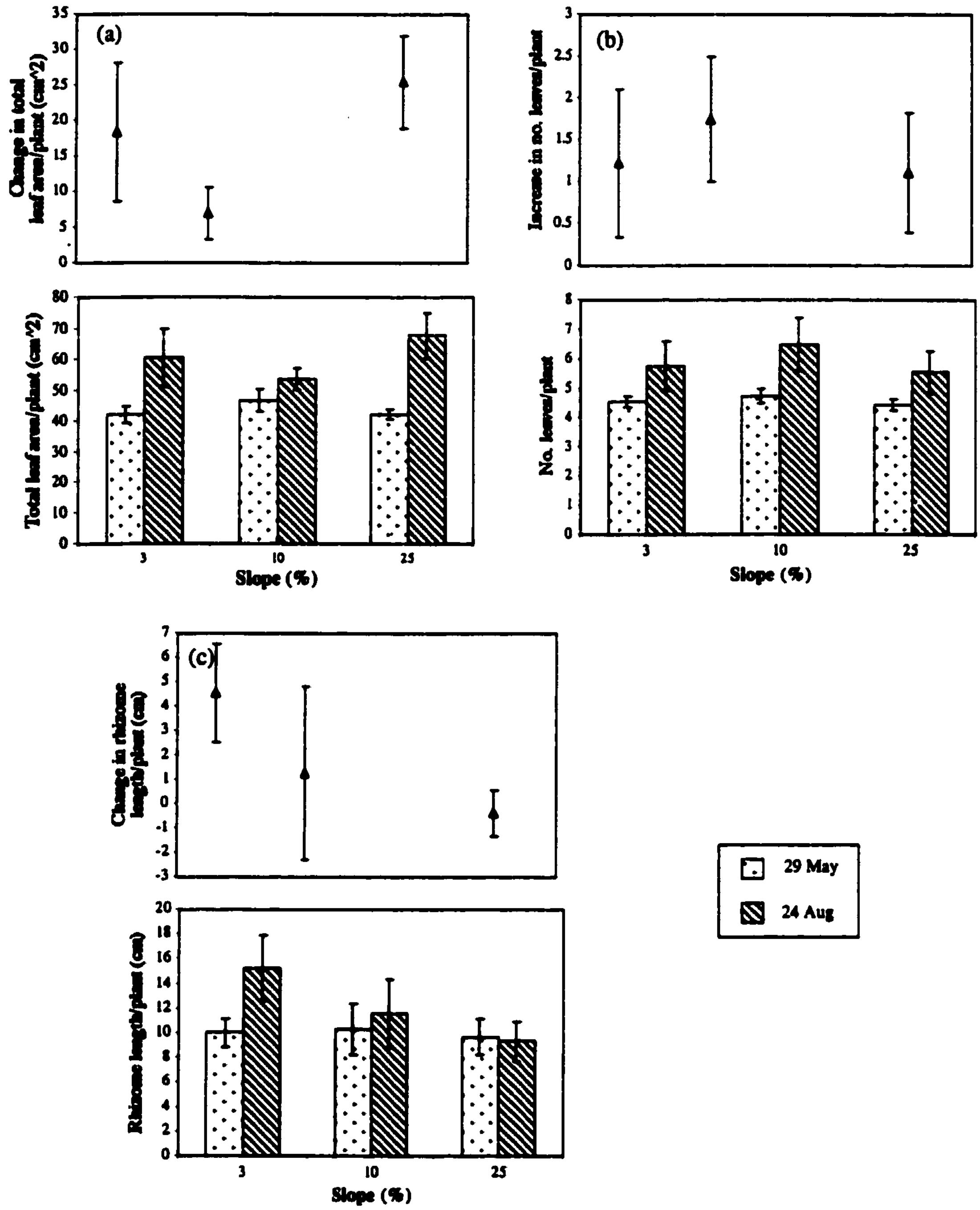

Figure 23a-c. The relationship between surface slope and plant growth as measured by change in (a) leaf area, (b) number of live leaves and (c) rhizome length. Error bars are +/-1 SE.

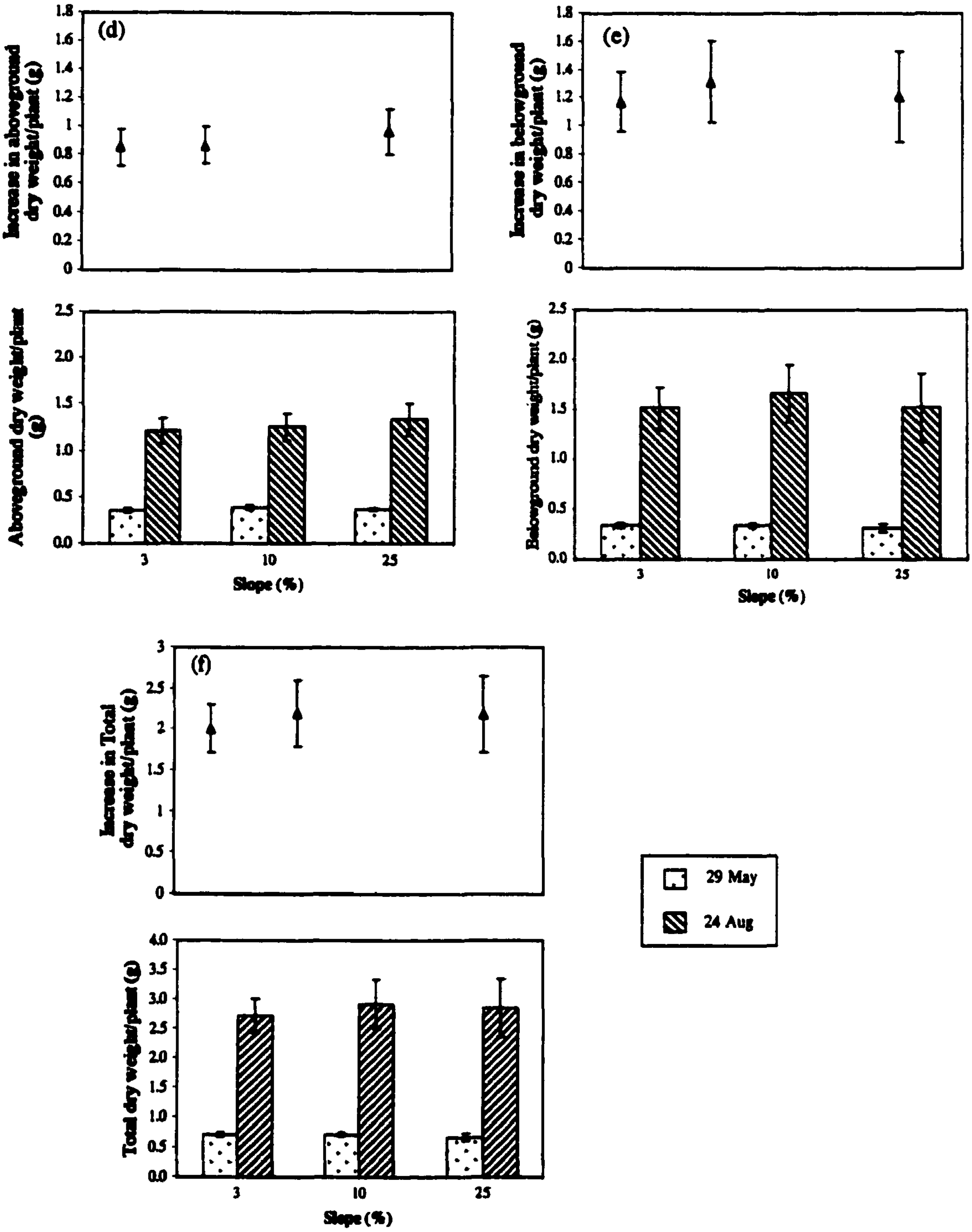

Figure 23d-f. The relationship between surface slope and plant growth as measured by change in (d) aboveground dry weight, (e) belowground dry weight, and (f) total dry weight. Error bars are +/-1 SE.

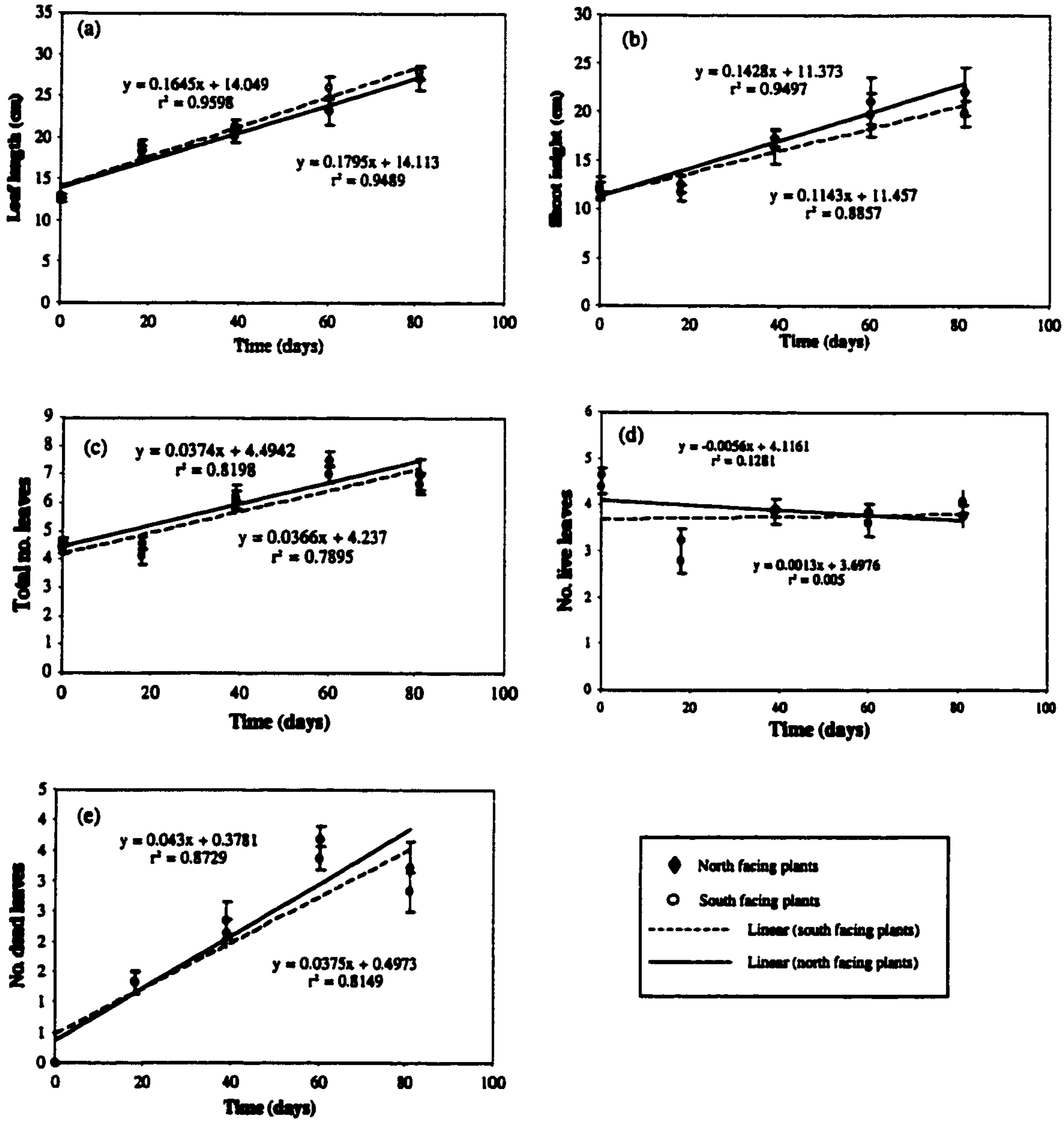

Figure 24. Increase in plant growth over time for plants facing north and south as measured by (a) leaf length, (b) shoot height, (c) total number of leaves, (d) number of live leaves, and (e) number of dead leaves. Error bars are +/-1 SE of the mean. Regression equation for south-facing plants is below the lines in all cases.

facing plants compared as indicated by changes in leaf length, shoot height and the number of dead and live leaves over time. In Figure 25, the growth over the summer season of plants at different slopes is illustrated. These figures show very little difference in the total growth or the growth rate of plants at different slopes or orientations.

IV. Discussion

The results of this experiment did not support my original hypotheses that marsh surface slope and north-south orientation will affect the first season's growth of *S. alterniflora* transplants. Slope and orientation had no significant effect on any of the growth characteristics I assessed (Fig. 22 and 23). Aside from a possible relationship between surface slope and rhizome growth, no trends were evident. I also found no correlation between the growth of the transplants and their elevations in the intertidal zone. This was expected, since I minimized the effect of this variable by locating all transplants within a narrow elevational range.

Other studies have found that the elevation at which *S. alterniflora* seedlings are planted on created salt marshes does affect their rates of growth and survival (Shisler 1990). In an experiment to test the effects of elevation on *S. alterniflora* growth in a constructed salt marsh in Texas, Webb and Dodd (1989) found significant differences in the height, density and survival of transplants growing at different elevations. They attributed this to the various lengths of time that plants were inundated by tidal waters. At my experimental site, all plants were within an elevation range of 21 inches, so that the amount of time they were inundated differed by at most only an hour each day. I might have seen differences in growth if transplants had been planted at a wider range of elevations, but this was not my goal. By placing all thirty pots within such a narrow band of elevation, I minimized the effects of this variable on plant growth.

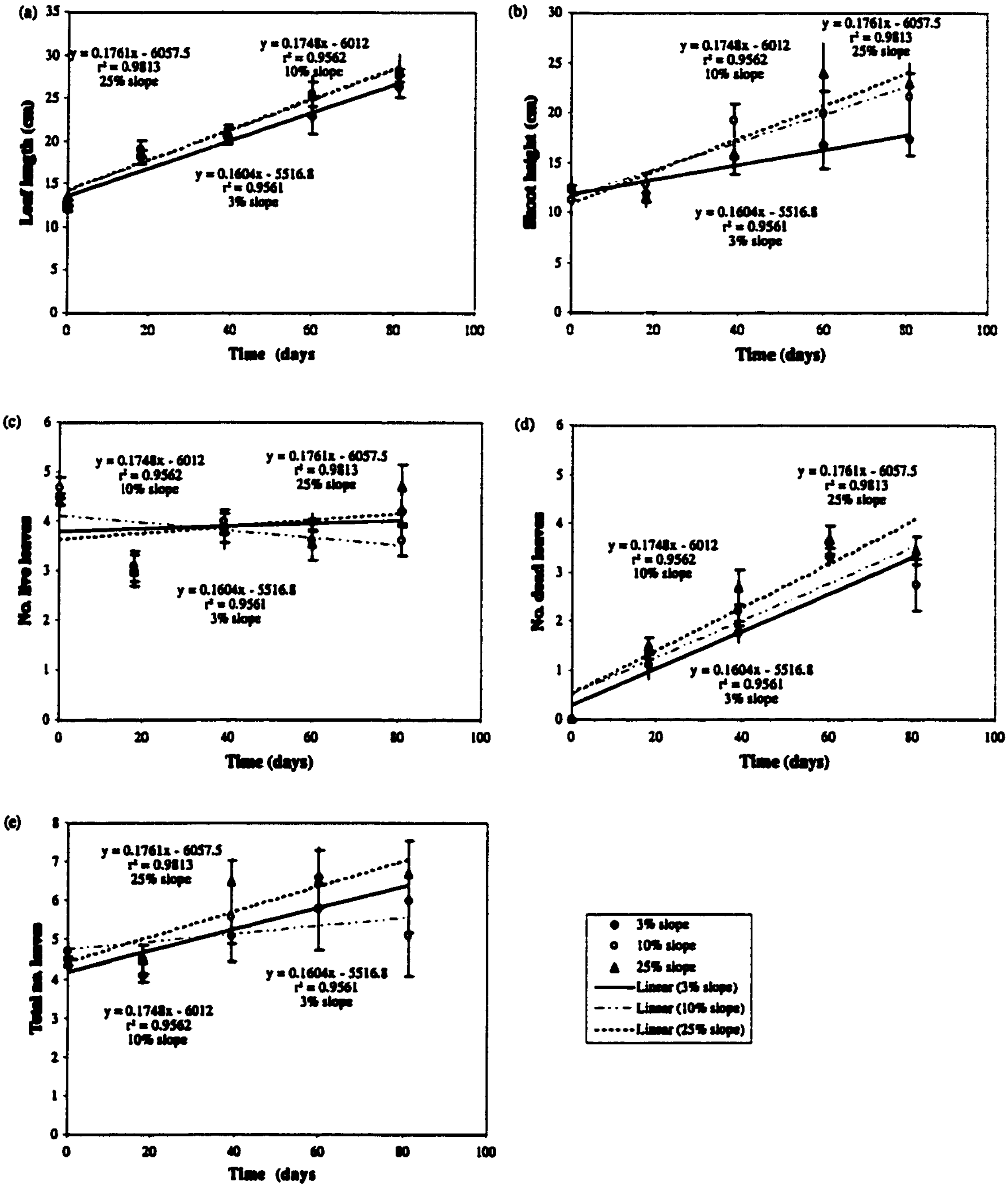

Figure 25. Increase in plant growth over time for plants growing on different surface slopes as measured by (a) leaf length, (b) shoot height, (c) total number of leaves, (d) number of live leaves, and (e) number of dead leaves. Error bars are +/-1 SE of the mean.

The fact that there were no significant differences in above- or belowground plant growth between plants on north-facing and south-facing slopes indicates that all plants were receiving adequate sunlight for growth. In terrestrial systems, south-facing slopes typically have greater temperatures than north-facing slopes, which can contribute to increased plant growth (Aber and Melillo 1991). I recorded the temperature of the soil in all the experimental pots and found no significant difference in temperature between north-facing and south-facing pots. Because the plants were growing in the low marsh zone, tidal waters covered the pots twice a day, and probably had a stabilizing effect on soil temperatures.

I chose 3%, 10% and 25% slopes for this experiment because they were representative of the range of slopes I had observed in natural fringing salt marshes (3.8%-25%). The range of slopes I had measured in the six constructed marshes was somewhat larger than that of the natural marshes. One of the constructed salt marshes had a surface slope of only 1%, and another was quite steep (33% slope). Given that there is such a wide range of slopes in both natural and constructed salt marshes in the area, and given the positive correlation (r=0.935) I had observed between surface slope and aboveground production in fringing marshes from the Saco River to the Great Bay Estuary (Figure 6) (discussed in Chapter 2), I was surprised to find that in my experiment, I saw no effect of slope on plant growth. Although as Figure 21 illustrates, this positive slope/aboveground biomass relationship was not observed in the eleven sites I sampled in the Great Bay Estuary. In the two most steeply sloped sites, where the surface slope was greater than 15%, aboveground biomass values were low (<300 g/m^2).

It is possible that it is not the slope of the marsh surface itself, but some other, related factor that is responsible for the differences in plant growth I observed in natural marshes. Several environmental parameters have been shown to affect the growth and production of *S. alterniflora* in natural salt marshes, including sediment oxidation status (Eh), salinity, sulfide concentrations, and nitrogen availability (Linthurst 1980; Morris and Dacey 1984; Howes et al. 1986; Teal 1986). In portions of the marsh that are inundated frequently by the tides, soils are typically more well drained and sediment oxidation rates are higher than in areas where soils have a higher peat content and are more waterlogged (Burdick et al. 1989). This leads to more rapid gas exchange between plant roots and the surrounding soil, which can result in higher rates of aerobic respiration in plant root cells in more well drained soils. In addition, the availability of oxygen in soils has been shown to influence nitrogen uptake rates by plant roots (Morris and Dacey 1984), and nitrogen is a limiting nutrient for *S. alterniflora* (Teal 1986).

However there is a trade-off in well-drained soils between greater oxygen content and nutrient levels. Salt marshes that have been constructed with soils that are predominantly sand have nitrogen levels that are too low to sustain vigorous plant growth, as sand does not retain nutrients due to its low cation exchange capacity (Shisler and Charette 1984; Broome et al 1988). This is why current recommendations are that created marsh soils contain a mixture of sand, clay and organic rich soil (Bosworth and Short 1993). And in natural fringing marshes, sites with very steep slopes (>15%) may drain too quickly, so that plants cannot obtain the water and nutrients they need for optimum growth.

The trends in plant growth I observed in natural salt marshes of different surface slopes are therefore probably not due directly to the slope of the marsh surface, but to the characteristics of the soil in which the plants are growing. Generally, more steeply sloped fringing marshes are better drained, resulting in more oxidized soils (Burdick et al. 1989), and experience a greater "tidal subsidy," which brings nutrients to plant roots and flushes away waste materials (Odum 1980). However there is an upper limit to the slope/production relationship observed in natural fringing salt marshes. In this experiment, although the slope was varied, all edaphic factors were controlled, as the soil was identical in all 30 pots. This could explain why I did not observe any differences in plant growth.

Another possibility is that if plants had not been harvested at the end of the first growing season, but had overwintered and grown for another year, differences in growth may have been evident after the second growing season. Transplanting causes stress to plants, and I observed that the newly planted *S. alterniflora* did not produce new leaves for several weeks after transplanting (Fig. 24d). In addition, at the time of harvest, plants growing in the pots were substantially smaller in size than plants growing nearby in the marsh. Giving the plants an earlier start might help lessen the problem of transplant stress. At one constructed site in the Great Bay Estuary, researchers found that planting in the late fall gave plants a head start in spring growth (Short, pers. obs.). Plant growth at this constructed site during the following summer season was much greater than at sites where transplanting had taken place in the spring.

The results of this experiment did not support my hypothesis that surface slope and north-south orientation affect the first season's growth of *S. alterniflora* plants transplanted to created marsh soils. However, because this was a one-year study, I cannot draw any conclusions concerning the long-term growth of *S. alterniflora* transplants in constructed marshes of different slopes and north-south orientations. Although I observed no differences in the growth of transplants during the first growing season, further research is needed to determine whether it is necessary to consider these two environmental parameters as one designs created salt marshes and selects sites for their construction in New England.

CHAPTER IV

USING FUNCTIONAL TRAJECTORIES TO MODEL CONSTRUCTED SALT MARSH DEVELOPMENT IN THE GREAT BAY ESTUARY, ME/NH, USA

I. Introduction

There has been growing awareness in recent years of the value of tidal wetlands to the economy and sustainability of coastal ecosystems in the Gulf of Maine (Cornelisen 1998). However, development pressures on coastal environments have been at odds with the goal of maintaining the ecological integrity of marshes, and anticipated growth and sprawl in the region is likely to further exacerbate the problem. Coastal salt marsh habitats in particular have been susceptible to a variety of anthropogenic impacts, including point and nonpoint source pollutants, invasive plant species, tidal restrictions, ditching, draining, and dredging of nearby waterways (Nixon 1982; Cornelisen 1998). In addition, salt marshes are still vulnerable to permitted destruction in cases where impacts are deemed by regulators to be unavoidable due to necessary coastal development. These permitted impacts continue, despite estimates that only 50-75% of the coastal wetlands present before colonial times remain in the states of Massachusetts, Maine and New Hampshire (Cook et al. 1993).

The growth of coastal populations that has occurred over the past thirty years in northern New England is expected to continue (Culliton et al. 1990). The population of the coastal counties of New Hampshire almost doubled from 1970-2000, and even in a state like Maine, which is considered by many to be "remote," growth continues (Culliton et al. 1990). This has been evident in the southern Maine coastal town of Wells, which grew 28% from 1970-96 (SMRPC 1996). In response to development pressures that have accompanied the growth, there have been increasing efforts to restore salt marshes or create new ones to mitigate for permitted impacts or historic damage. Unfortunately, it is unclear to what degree constructed wetlands actually function like natural ones, and if they do, how long it takes for a constructed marsh to approximate the functions of a natural marsh.

A goal of this study was to evaluate the success of six constructed (both created and restored) salt marshes in the Great Bay Estuary, located along the Maine/New Hampshire border. All of the sites were constructed to compensate for impacts to natural salt marshes in the area. Although constructed salt marshes located further south along the East Coast have been studied, little research had been conducted to assess the success of projects as far north as Maine and New Hampshire. Constructed salt marshes in northern New England are generally smaller in size than those found further south, and they are subject to more severe weather conditions, including winter ice formation and ice movement onto marsh surfaces.

Determining whether a constructed wetland project is a success can be difficult because no standard method exists for determining success or failure, and in fact, there is still no agreed upon definition of success (Roberts 1993; Short et al. 2000). We used Quammen's (1986) definition of functional success to guide our evaluation of the constructed salt marshes in the Great Bay Estuary. After reviewing a range of studies that evaluated wetland mitigation projects, she categorized them as either achieving compliance success (meeting permit requirements) or functional success (replacing the functions of the impacted wetlands). She found that most studies of mitigated wetlands addressed their compliance success, but not functional success, and argued for comparisons of created or restored wetlands with control sites in "long-term, well-designed studies" (Quammen 1986). Her definition of success based on wetland functions agrees with the U.S. government's "no net loss" policy for wetlands, which specifies that impacted wetland functions should be replaced by the created or restored sites (Brinson and Rheinhardt 1996; Zedler 1996).

To study the functional success of a constructed wetland, the desired functions of the system first must be identified. Brinson and Rheinhardt (1996) defined wetland functions as ecosystem activities or processes that occur over time and do not depend on societal perceptions; that is, they continue to occur whether or not people care about them. The U.S. Army Corps of Engineers (1995) defines wetland functions similarly, as the self-sustaining properties of a wetland ecosystem that exist in the absence of society.

Early studies designed to assess whether constructed salt marshes are equivalent to natural marshes in terms of their functions produced mixed results, but in general the success rate of projects was low (Race and Christie 1982; Race and Fonseca 1996). Evaluating the functional success of created and restored salt marshes has continued to be an active area of research among estuarine ecologists. Carefully designed scientific studies where a created or restored site is paired with one (or sometimes two) reference site(s) and their structures and functions compared have been conducted in many coastal states, including California (Zedler and Callaway 1999), Connecticut (Sinicrope et al. 1990), Maine and New Hampshire (Short et al. 1998), North Carolina (Levin et al. 1996; Craft et al. 1999), Virginia (Havens et al. 1995), and Washington (Simenstad and Thom 1996).

To see if the functions of created and restored salt marshes follow any particular patterns of development over time, some investigators have explored the use of functional trajectory models, also known as performance curves. To build these models, two approaches have been used. In the first, data are collected at a single constructed site over a period of many years, whereas in the second, data are collected from many constructed sites of varying ages at one point in time. In both cases, the constructed sites are compared to one or more reference sites. As time goes on, the level of function of the created or restored wetland should approach that of the natural, reference wetlands if it has been appropriately designed and built (Kentula et al. 1992). Kentula states that trajectories could be used to determine how frequently to monitor projects (by noting yearly changes of variables of interest) and to address management questions. Important questions are: (a) what level of function is achievable for natural wetlands and projects in particular settings? (b) do the projects achieve the same level of function as natural wetlands? (c) how long does it take for projects to achieve the desired level of function? and (d) how can monitoring be timed so as to obtain the most reliable information (Kentula et al. 1992)? Whether development of functions in constructed marshes follow predictable trends is still being debated, as is the potential value of trajectory models in assessing constructed salt marsh projects (Zedler and Callaway 1999; Simenstad and Thom 1996).

The constructed salt marshes we evaluated in the Great Bay Estuary ranged in age from 1-14 years in age, which allowed us to investigate whether the functions we assessed showed developmental trends over time. By assessing one or more indicators associated with a function and correlating the level of the indicator with the ages of the constructed marshes, we could determine whether the level of function of the created wetland was approaching that of the natural, reference marshes.

The specific objectives of this study were to (1) compare several of the functions of created fringing salt marshes to those of natural fringing salt marshes in the Great Bay Estuary, and (2) determine if the relationship between the ages of the constructed sites and their levels of function could be modeled using functional trajectories.

II. Materials and Methods

A. Description of study sites

The Great Bay Estuary is a complex embayment on the Maine-New Hampshire border that has high tidal energy and includes mud flat, eelgrass, channel bottom, rocky intertidal and salt marsh habitats (Short 1992). The Estuary's salt marshes are either the typical New England salt marsh type, larger meadow marshes found primarily at the mouths of most of the rivers and dominated by high marsh, or the smaller fringing salt marsh type, narrow in width and forming a discontinuous band around the periphery of the Estuary. The six constructed salt marshes were all fringing salt marshes, located along the edges of the Estuary's bays, rivers or streams (Fig. 26). Fringing marshes in this area typically have greater surface slopes, less soil organic matter content, and plant communities comprised of greater proportions of *Spartina alterniflora* than nearby meadow marshes. They are also more variable in terms of physical characteristics and levels of function than larger meadow marshes (Morgan and Short 2000).

As mentioned earlier, most of the constructed sites we studied had been created or restored as mitigation for natural salt marshes that were destroyed as a result of development projects, including the expansion of a private marina (site 3) and the Port of New Hampshire (sites 1, 4, 5 and 7). Another salt marsh was constructed at a site where an existing natural marsh had been impacted when a loading platform for a retail store was built. The state had required that the structure be removed and the site be restored to salt marsh habitat (site 31). At the time of our study, the constructed sites ranged in age from one to fourteen years.

B. Selecting reference sites

Based on past experience and the scientific literature, we first developed a list of the functions and values of New England's salt marshes (Table 1) and selected several of the functions for study, including primary production, sediment trapping and binding, organic matter accumulation, and maintenance of plant diversity. Next we chose a number of natural sites to serve as reference sites. We based our choice of reference sites on several physical characteristics that had been observed to correspond with the functions that we were interested in studying (Gleason et al. 1979, Stumpf 1983, Jacobson and Jacobson 1989, Kastler and Wiberg 1996). These physical characteristics were the north-south orientation of the site, percent surface slope, fetch, width and length.

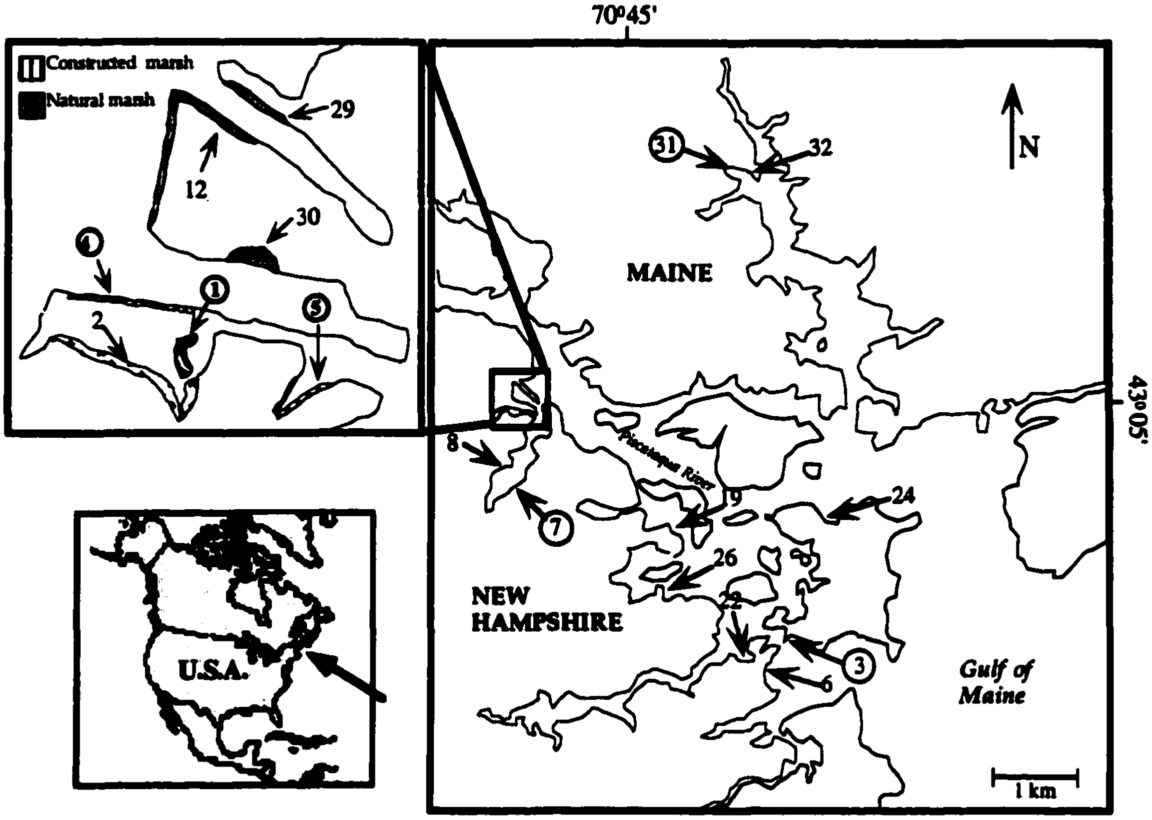

Figure 26. Location of constructed and reference sites within the Great Bay Estuary. Constructed sites are indicated by circled numbers.

Measurements were made first at the six constructed sites so that the range of values for each physical characteristic could be determined. We then collected similar data from 26 natural fringing marshes in the Estuary.

North-south orientation was determined by taking a compass reading while facing open water. Values were then converted to a linear north-south scale, from 0° (north) - 180° (south), by subtracting readings greater than 180° from 360°. Surface slopes were measured along three transects running perpendicular to the upland edge of the marsh. Slopes were determined using a water level attached to a hose and a 50-m tape, and measurements were averaged. Fetch measurements were made using a rangefinder for smaller distances or a U.S.G.S. topographic map for greater distances. We measured the distance between the marsh edge and the nearest land across the water in the perpendicular direction, as well as the distances to the nearest land 45° to either side of the perpendicular line. The three values were averaged to determine mean fetch. The length and width of each salt marsh was measured with a 50-m tape. The mean width of each marsh was calculated from measured widths along five equally spaced transects which ran from the upland to the edge of the marsh along the water.

The physical characteristic data collected from the constructed and natural salt marshes were reviewed to identify reference sites for each created or restored site. The data from all 32 surveyed sites were analyzed using Principal Components Analysis (PCA). The PCA resulted in the sites being sorted so that those most similar in terms of the physical characteristics measured were clustered together on a two dimensional graph (Fig. 27). We then located the points representing each and identified the two natural marshes closest to each of these constructed sites on the graph. The six constructed sites and 11 reference sites selected for study are shown in Figure 26.

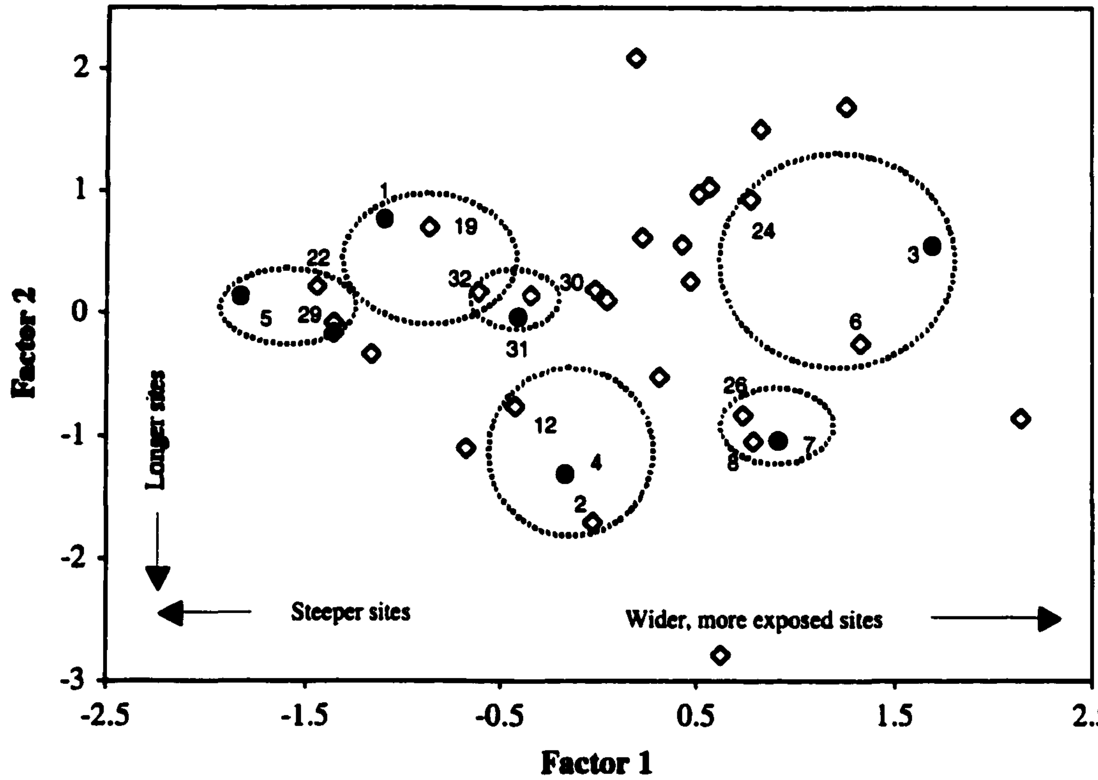

Figure 27. Principal Components Analysis of the physical characteristics of created and natural salt marsh sites. Filled circles represent constructed marshes; diamonds represent natural marshes. The two reference sites closest to each constructed site on the PCA diagram are circled. Each constructed site and its two reference sites are labeled with their site numbers. Loadings of each variable on the final rotation are listed in Table 9.

C. Measuring salt marsh functions

We next measured indicators of each of the four chosen salt marsh functions at the six created/restored and the 11 reference sites (Table 7). An indicator is a variable closely associated with a particular wetland function. Indicators should be sensitive enough to represent functional performance and be relatively easy to measure (Kentula et al. 1992). Measures of wetland structure (eg. soil organic matter) are often used as indicators instead of direct measures of function (eg. organic matter accumulation) due to economic and time constraints. However these structural measurements can become measures of function if they are made over time (Kentula et al. 1992).

The peak aboveground standing crop served as an indicator for the function of primary production. It should be noted that using the standing crop as an indicator of primary production underestimates true aboveground net production by 10-15% because it does not account for the turnover of new plant tissues during the growing season (Nixon and Oviatt 1973). At the reference sites and at the two oldest constructed sites, all vascular plant vegetation was clipped in six randomly distributed 0.5 m^2 quadrats at the end of the growing season. Algae were removed from the sample. Live plants were separated from dead material and then dried at 60°C for 48 hr. To avoid adversely impacting the still sparsely-vegetated constructed sites, aboveground biomass was estimated from percent cover and shoot area according to the equation: Biomass = 0.658 * (% cover) + 0.557 * (Shoot area) (developed by Short et al. 1998)[3].

Soil organic matter content was measured by loss on ignition. Three cores (5 cm deep, 3.5 cm diam.), evenly spaced along the middle of the site, were sampled from each marsh. Percent organic matter in the sediment was then determined from weight loss upon combustion in a muffle furnace (450°C for 4 hr) (Craft et al. 1991).

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[3] Shoot area = 0.776 * shoot height -2.26 for two leaves, +0.49 for three leaves, +6.57 for four leaves, +11.24 for five leaves, +45.29 for 6-8 leaves; $r^2 = 0.933$.

Table 7. Salt marsh functions studied and indicators assessed at constructed and reference marsh sites.

Function	Indicator
Primary production	Annual standing crop (above and belowground biomass/area/time)
Soil organic matter accumulation	Soil organic content over time (grams organic matter/area/time)[1]
Maintenance of plant diversity	Species richness (no. species/site); relative abundance (percent cover of plant species)[1]
Sediment filtration, trapping and binding	Sediment accumulation on discs (grams sediment/area/time)

[1] These measurements were made only once in this study, so were not tracked over time.

The ability of sites to trap and bind sediments was assessed by measuring the amount of sediment accumulated on the marsh surface over a period of time. Sediment was collected on mylar discs (8 cm diameter) distributed on the surface of each marsh for two experimental intervals of three weeks, one beginning on July 18 and the second beginning on August 7. Five traps (Fig. 4) (modified from Reed (1989)) were evenly spaced in the middle of each marsh, along a line running parallel to the water's edge.

The ability of the marsh sites to maintain a diverse plant community was assessed by determining the species richness and relative abundance of vascular plants at each site. Sampling occurred along at least three band transects running from the water's edge to the upland edge. Quadrat size was 1 m^2 and the distance between transects was 20 m at most sites. To more adequately sample smaller sites, quadrat size and the distance between transects were reduced while maintaining similar sampling intensity. Percent cover of all species in quadrats was estimated visually using the following cover classes: 0%, $0\% < x \leq 1\%$, $1\% < x \leq 5\%$, $5\% < x \leq 10\%$, $10\% < x \leq 20\%$, and continuing above 20% in 10% increments up to 100%. Total percent cover per quadrat did not exceed 100%.

D. Data analysis

Mean values for the six created and eleven natural sites were calculated for aboveground production, sediment deposition and soil percent organic matter, and were then compared using analysis of variance (ANOVA), with 'group' as a blocking factor. A site's 'group' designation referred to the matching of each constructed site with its two reference sites (Fig. 27). Plant diversity data were analyzed to compare the mean number of species per site and the mean species diversity as measured by the Shannon-Weiner index (H) in constructed and reference marshes (Goldsmith et al. 1986). In addition, plant species composition and abundances at each constructed and natural site were compared using Detrended Correspondence Analysis, a type of ordination analysis (Hill and Gauch 1980).

The relationship between the ages of the created/restored sites and their level of function was explored by plotting the data for each indicator measured, with age of the constructed sites as the independent variable. The objective was to see if the data fit trajectories that could be used to describe general patterns in the development of the constructed sites over time. We determined that the 95% confidence intervals around the means of the indicators (dependent variables) measured at the reference sites would be the desired outcome values for the constructed sites. After observing any apparent trends in the data, we fit nonlinear models to the constructed site data (SYSTAT 9). The maximum value for the dependent variable (or minimum, in the case of sediment deposition) was set at the 95% confidence interval around the mean of the eleven reference sites. Models tested for each indicator were selected or rejected based on their coefficients of determination (r^2) and on whether they made sense ecologically, given our current understanding of constructed salt marsh development and salt marsh ecology. Thus, the trajectory models show the degree to which the dependent variables (indicators) from the constructed sites approach reference values and in addition, the rate at which this happens.

Aerial photographs indicated that reference site 30 was not present before the construction of a road across Inner Cutts Cove 22 years earlier, so after nonlinear models were developed using constructed site data, values for site 30 were plotted to see how they compared to the trajectories.

III. Results

A. Selection of reference sites

Results of the initial study of the physical characteristics of the six constructed marshes and 26 natural salt marsh sites (potential reference sites) are summarized in Table 8. All of the sites were relatively narrow in width (29 m or less), and had distinct north-south orientations which ranged widely from facing due north (0°) to due south

Table 8. Summary of results of physical characteristics measured at 32 salt marsh sites (six constructed and 26 natural) in the Great Bay Estuary. Numbers are means +/-1 standard error.

	Length (m)	Width (m)	North/south orientation (°)	Fetch (m)	Surface slope (%)
All sites (n=32)	100 +/-11	11 +/-1	105 +/-10	296 +/-42	10 +/-1
Constructed sites (n=6)	90 +/-27	9 +/-3	114 +/-29	181 +/-92	9 +/-3
Natural sites (n=26)	102 +/-12	11 +/-1	103 +/-10	323 +/-46	10 +/-1

Table 9. Principal Components Analysis loadings of five physical characteristics measured. Total variability accounted for by axis 1 was 44.4%, and for axis 2 axis was 20.1%.

Variable	Factor 1	Factor 2
Length	0.423	-0.852
Width	0.871	0.045
North/south orientation	0.321	-0.057
Fetch	0.722	0.522
Surface slope	-0.811	0.047

(180°). The average fetch varied considerably from site to site, as some of the marshes were on the edges of bays, whereas others were located along very small creeks. In general, constructed sites were located in more protected areas, although the fetch at created marsh site 3 was quite large (583 m). The surface slope of the 32 marshes ranged from 1 - 25%, with a mean of 10%.

Principal components analysis showed that 64.5% of the variability in the data set is explained by the first two components (axes) (Table 9). The component loadings for each variable (physical characteristic measured) show that marsh width, fetch and surface slope had the greatest influence on where sites were plotted on the x axis (factor 1), and length was most important in determining where sites would lie on the y axis (factor 2). The two natural sites on the graph that were the shortest distance from each constructed marsh site on the graph were chosen as reference sites for that constructed site (Fig. 27).

B. Comparison of constructed and reference site functions

There was high variability among both constructed sites and reference sites for most of the indicators measured (Fig. 28). Although mean values for constructed and reference sites were significantly different for aboveground production, amount of sediment deposited and soil organic matter content, there was overlap between values for some individual reference and constructed sites.

Mean values of constructed (n=6) and reference (n=11) sites were compared using ANOVA, with 'group' (representing each group of one constructed and two reference sites) included as a blocking factor. Both aboveground biomass production (P=0.0096, block P=0.0703) and percent soil organic matter (P=0.0001 log transformed data, block P=0.2118) were significantly greater at reference sites (Fig. 28a, b), but the average amount of sediment deposited on the surface of constructed marshes over the time measured was greater than that deposited on reference sites (P=0.0086, block P=0.2466) (Fig. 28c). Because the relative amounts of sediment deposited on the created and

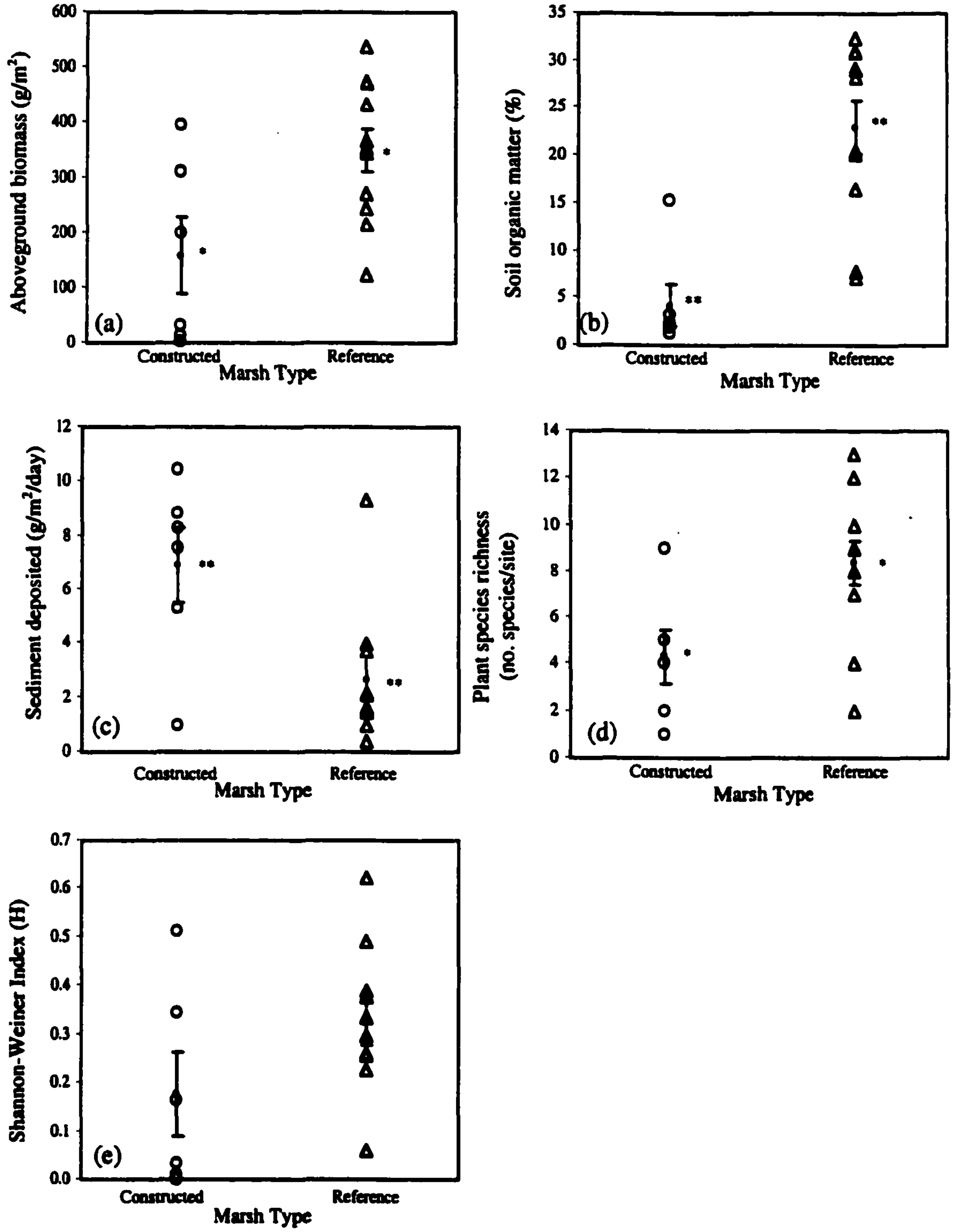


Figure 28. Comparison of functional indicators between constructed and reference marsh sites. Small shaded markers are means +/-1 SE. Means that are significantly different according to the ANOVA with blocking by group are followed by asterisks; * $P < 0.05$, ** $P < 0.01$.

reference sites were similar over the two sampling periods, the results of the two trials were averaged.

The mean number of plant species at reference sites (11) was significantly greater than at the created/restored sites (6 species) (P=0.0201) (Fig. 28d). The range of values was quite large for reference sites, from two species to 13 species per site. In addition, the oldest constructed marsh (site 31) had greater species richness than the mean of the reference sites, and two of the reference sites had lower species richness than the mean of the constructed sites. Even with this degree of overlap we found a significant difference in species richness because we were able to objectively select reference sites. To compare plant diversity between constructed and reference marshes using the Shannon-Weiner index (H), we randomly selected nine quadrats from among those sampled at each site, as this was the minimum number sampled at any site. We found no difference in diversity as measured by this index (P=0.1155) (Fig. 28e).

With the exception of the oldest constructed site, the plant communities of all of the constructed sites were dominated by *Spartina alterniflora*, the dominant low marsh species in Maine and New Hampshire. The fourteen year old constructed site contained *S. alterniflora* and the high marsh plant *Spartina patens* in equal amounts. *S. patens* was also present in constructed site 3 (six years old), but comprised less than 1% of the percent cover. The proportions of the dominant low and high marsh plant species varied among reference sites, although the plant communities at all but three sites contained more *S. alterniflora* than high marsh species (*S. patens*, *Distichlis spicata* and *Juncus gerardii*) (Table 10).

Results of the ordination analysis (Fig. 29) indicate that with the exception of the oldest constructed marsh (site 31, 14 years old), all of the constructed sites are clustered to the left along the abscissa, indicating that their species compositions were different from those of the reference sites. The species composition of reference site 30 (identified as ≤22 years old) was most similar to that of the five youngest constructed sites.

Table 10. Percent cover of dominant low marsh (*Spartina alterniflora*) and high marsh (*S. patens, Juncus gerardii & Distichlis spicata*) plant species at constructed and reference salt marsh sites.

Site	Type	Percent cover: *Spartina alterniflora*	Percent cover: *S. patens, Juncus gerardii & Distichlis spicata*
1	C	11	0
3	C	38	<1
4	C	1	0
5	C	8	0
7	C	42	0
31	C	29	37
2	R	20	47
6	R	22	22
8	R	35	21
12	R	34	11
19	R	26	12
22	R	35	5
24	R	25	9
26	R	19	38
29	R	26	13
30	R	55	1
32	R	5	84

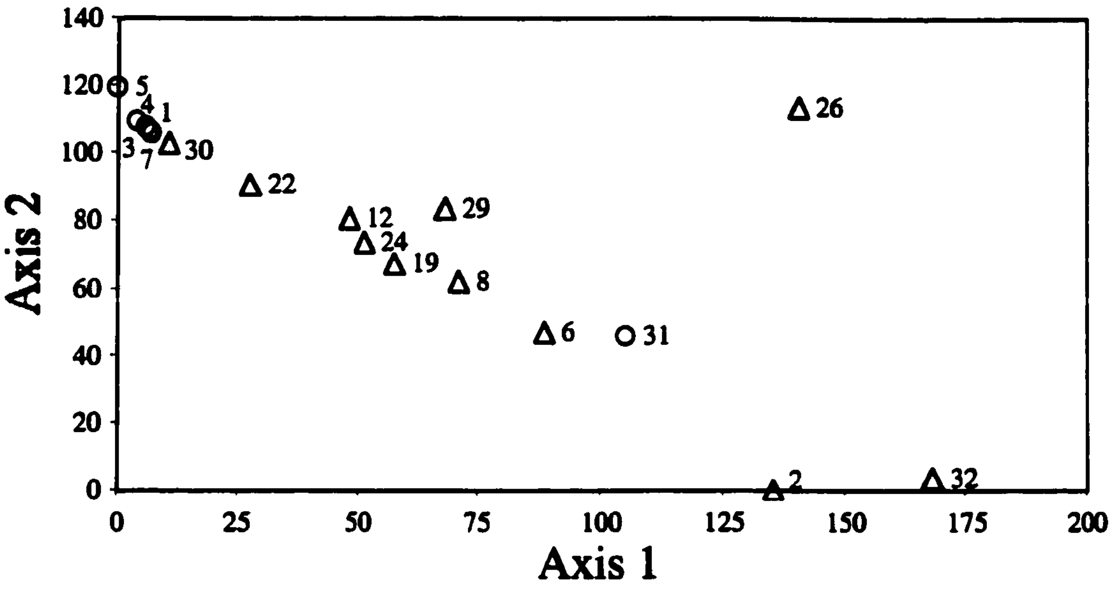


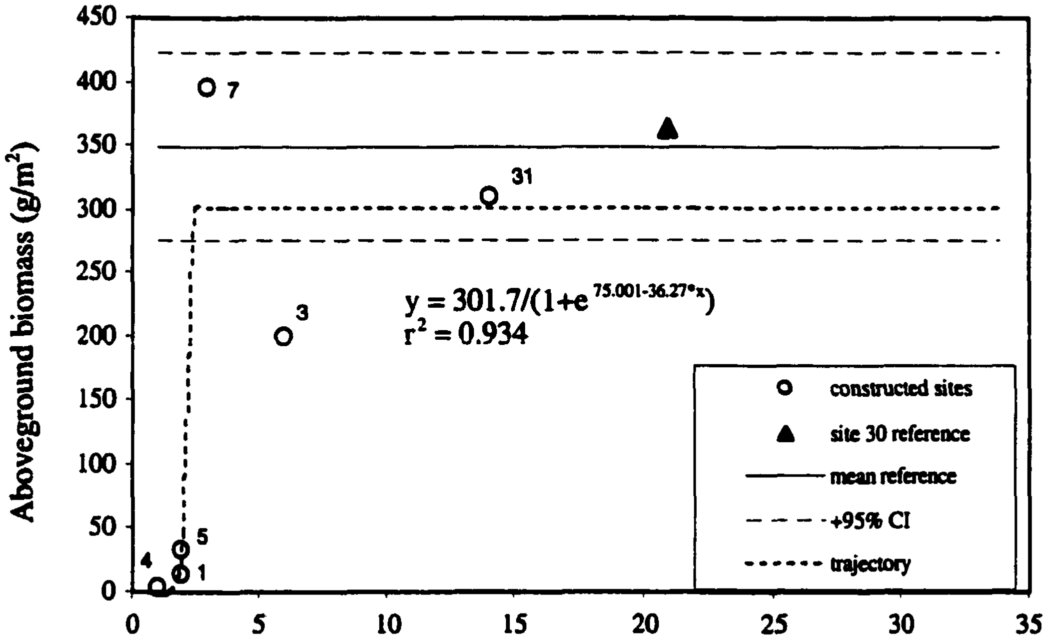
Figure 29. Ordination analysis of plant species percent cover data at six constructed and eleven reference salt marshes. Constructed sites are represented by open circles, reference sites by triangles.

C. Functional trajectory models of marsh development

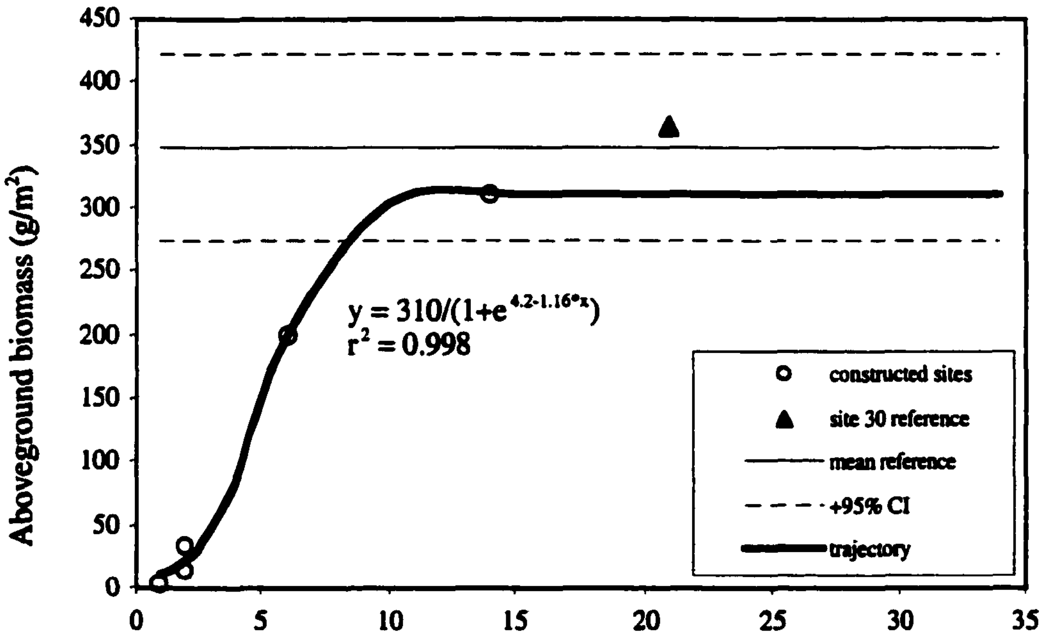
Functional trajectory models for aboveground biomass, soil organic matter content, sediment deposition and plant species richness are illustrated in Figure 30-33. Constructed marsh values for all of these indicators followed a discernable pattern as indicated by the regression line. The other indicator of plant diversity, the Shannon-Weiner index (H), did not show any relationship with the increasing age of constructed marsh sites (Fig. 34).

Peak season aboveground biomass, the indicator for primary production, followed a logistic curve, leveling off at 310 g/m^2, a value that is less than the mean of the reference sites (348 g/m^2), but that is within the 95% confidence interval around the mean (Fig. 30). Aboveground biomass values at constructed site 7 were much greater than those of the other constructed sites, and greater than two thirds of the reference sites. Because we believe this to be due to excess nitrogen input to North Mill Pond from sewage waste, we present trajectories calculated with the value from site 7 included (Fig. 30a), as well as with the site 7 value excluded (Fig. 30b). The percent soil organic matter curve was logistic, having been constrained to level off at 23%, the mean of the eleven reference sites (Fig. 31). Sediment deposition was much greater at younger constructed sites than at older constructed sites. The trajectory for this indicator followed a curve resembling that of exponential decay, but was constrained to level off at the reference site mean (2.6 $g/m^2/day$) (Fig. 32). The trajectory curve for plant species richness plateaued at 9.7 species, compared to the mean reference value of 8.4 species per site (Fig. 33).

Values for site 30, the reference site that was 22 or fewer years old, fell close to the calculated trajectory lines for the four functions illustrated in Figure 30-33. This was not the case for site 30's Shannon-Weiner diversity index value however, which fell outside of the 95% confidence interval around the reference site mean. Also, there was no pattern to the constructed sites' Shannon-Weiner index values (Figure 34).



(a)



(b)

Figure 30. Trajectory models for aboveground biomass at constructed sites of varying ages and at reference site 30. Also shown are the mean and 95% confidence interval for the selected reference sites. Fitted curve in (a) includes site 7 (site with nutrient input); curve in (b) does not include site 7. Points are labeled with site numbers in (a).

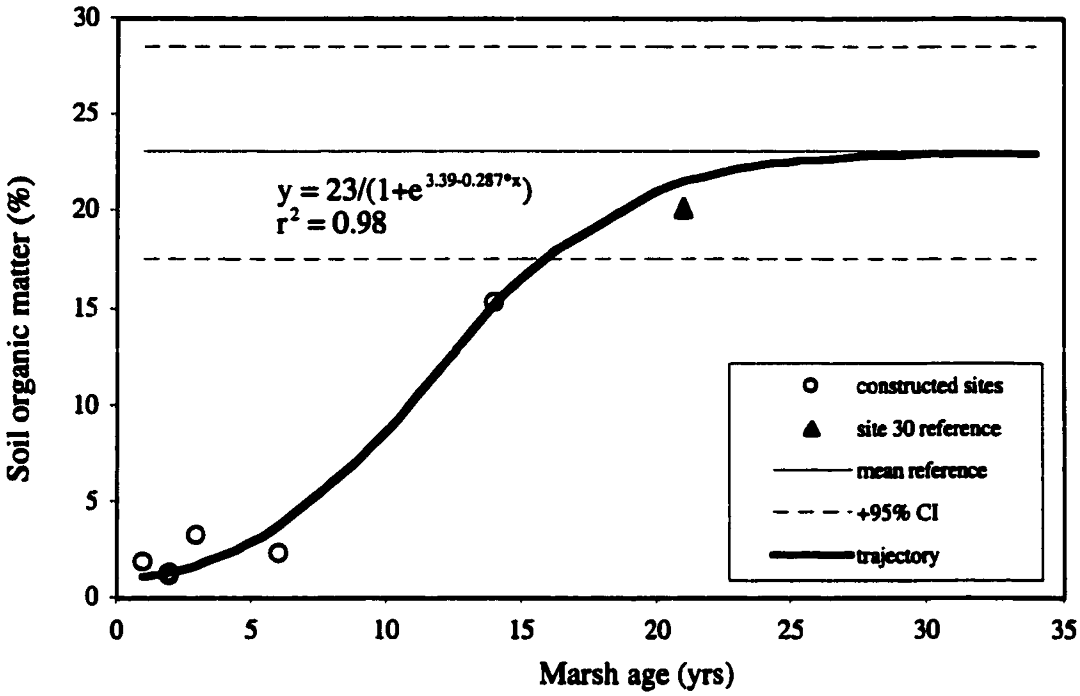


Figure 31. Trajectory model for soil percent organic matter content at constructed sites of varying ages and at reference site 30. Also shown are the mean and 95% confidence interval for the selected reference sites.

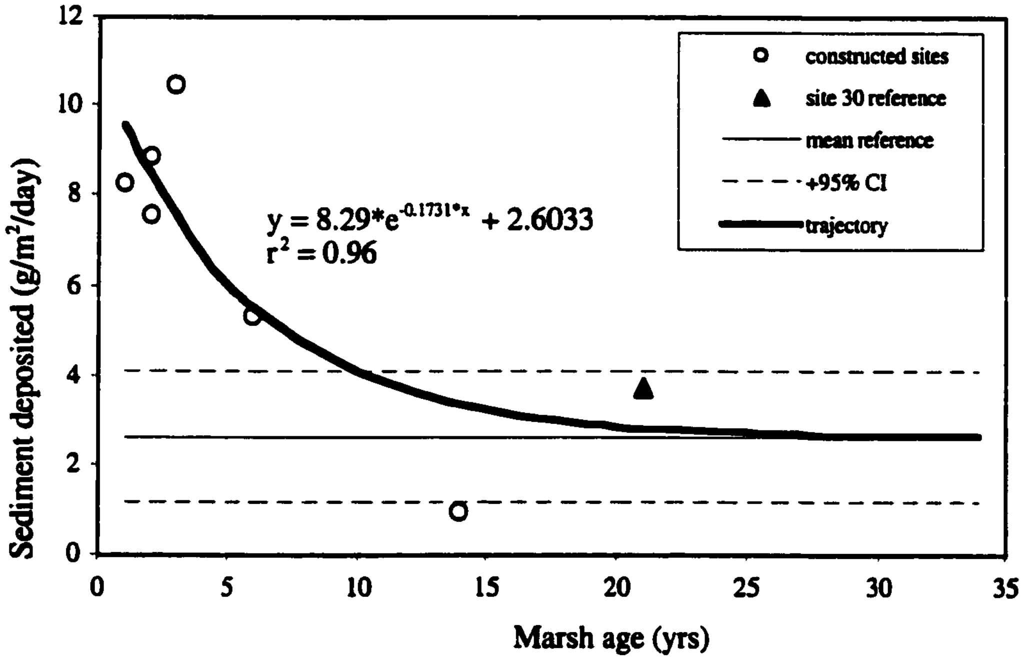


Figure 32. Trajectory model for sediment deposition at constructed sites of varying ages and at reference site 30. Also shown are the mean and 95% confidence interval for the selected reference sites.

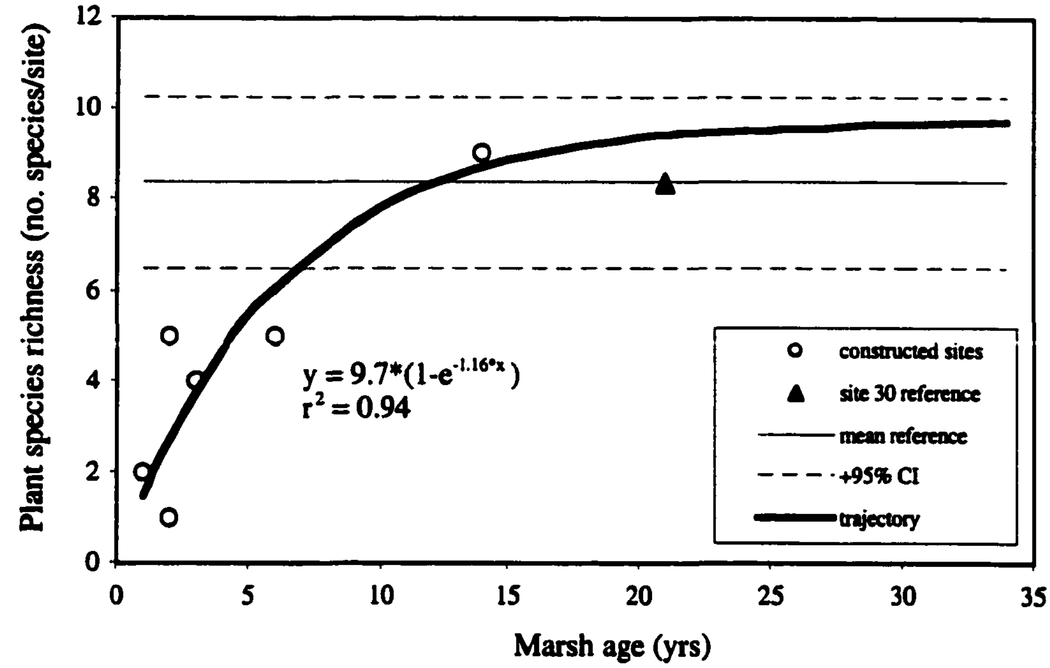


Figure 33. Trajectory model for plant species richness (no. species/site) at constructed sites of varying ages and at reference site 30. Also shown are the mean and 95% confidence interval for the selected reference sites.

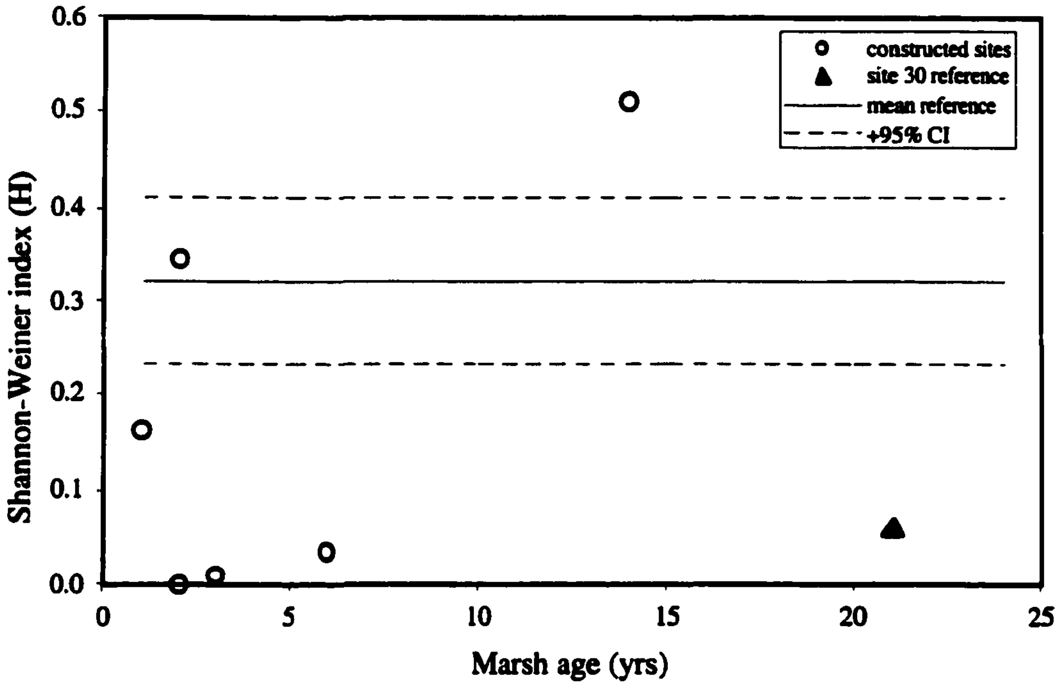


Figure 34. Plant diversity at constructed salt marsh sites of varying ages and at reference site 30 as calculated by the Shannon-Weiner diversity index (H). Also shown are the mean and 95% confidence interval for the selected reference sites.

IV. Discussion

A. Selection of reference sites

The six constructed sites we studied in the Great Bay Estuary were not all adjacent to each other, but rather were distributed throughout the Estuary (Fig. 26). We wanted to choose reference sites for comparison purposes that would represent natural fringing salt marshes in the Estuary, and that were similar to the constructed sites in terms of their physical characteristics. Underlying current methods of selecting reference sites is a basic assumption that there is a relationship between the physical characteristics of wetland systems and their functions (Brinson and Rheinhardt 1996), so we made this assumption explicit in our site-selection process.

Several of the physical characteristics we measured (surface slope, fetch, width, length) had been identified in the literature to correlate with the functions we were interested in studying (Gleason et al. 1979; Stumpf 1983; Jacobson and Jacobson 1989; Kastler and Wiberg 1996). The north-south orientation of the site was also included, as our previous investigations of fringing salt marshes had revealed a possible correlation between orientation and aboveground production. The physical characteristic data gathered from the constructed sites and the potential reference sites were then analyzed using PCA, which allowed us to quickly determine which of the natural sites were most similar to the constructed sites. PCA is a statistical method that reveals patterns in multivariate data (SYSTAT 9). Once the sites that were most similar to each other in terms of their physical characteristics were clustered together on a two-dimensional graph, the two natural sites most similar to each constructed site could easily be identified (Fig. 27). These eleven natural sites would serve as replicates when comparing the mean values for aboveground production, sediment deposition and soil percent organic matter between created (n=6) and natural (n=11) sites. Using PCA allowed us to be more objective in the reference site selection process.

Most studies evaluating the structure and functions of constructed salt marshes to date have compared a constructed site to one or at most two reference sites (e.g. Moy and Levin 1991; Havens et al. 1995; Craft et al. 1999; Zedler and Callaway 1999). Usually, the selection of reference sites is left up to the "best professional judgement" of experts who rely on their experience and the scientific literature (Brinson and Rheinhardt 1996). In published studies of created and restored salt marshes, the rationale for choosing reference sites most often given is that they are located nearby the study site(s) (e.g. Moy and Levin 1991; Chamberlain and Barnhardt 1993; Havens et al. 1995; Scatolini and Zedler 1996; Burdick et al. 1997; Melvin and Webb 1998). In some cases, researchers have explicitly stated that their choice of references sites was based on particular criteria, such as comparable sediment composition (Packard and Stiverson 1975), similar hydrology (Langis et al. 1991; Levin et al. 1996), or presence of vegetation typical of a well developed wetland (Chamberlain and Barnhart 1993). Melvin and Webb (1998) chose reference sites based on whether their size, exposure, region of the bay, and level of disturbance (by adjacent human development) were similar to what was observed at the created site.

The choice of reference sites is very important, as these sites are used as benchmarks against which constructed sites are evaluated. Because variability is high among natural salt marshes, the selection of reference sites can greatly affect a study's outcome. Whether a constructed site is deemed a success or a failure could depend on the natural site to which it is compared. This is evident in Figure 28, which illustrates the variability among natural reference sites in the Great Bay Estuary. Because there is currently no consistent protocol used in the selection of reference sites for comparison to constructed salt marshes, there is the potential for experimenter bias, albeit unconscious. We believe that a more quantifiable, objective approach would improve the reference site selection process, and that PCA is a logical choice for doing this.

It should be noted that in all cases, one of the two reference sites selected for each constructed site using PCA was also located near the constructed site in the Estuary. Natural sites that are "nearest neighbors" to constructed sites are often similar to them in terms of their physical characteristics.

In addition, in some highly developed coastal areas, natural salt marshes may not exist in close proximity to the constructed site being studied. The lack of nearby natural wetlands to use as reference sites is a problem for researchers working in many urban waterfront settings (Clark 1990). In some embayments along the southern coast of California, for example, there are no natural salt marsh acres remaining (Zedler 1988). This problem will become more common as the number of natural salt marsh acres continues to decline.

B. Comparison of constructed and reference site functions

Functional indicators for primary production, soil organic matter content and plant species richness had significantly lower mean values in constructed sites compared to reference sites (Fig. 28). Previous studies of constructed salt marsh sites along the East Coast have found that primary production rates in constructed sites are similar to those of reference sites after four or fewer years (Levin et al. 1996; Craft et al. 1999). The mean age of the constructed sites we studied was 4.7 years, so it appears that more time may be needed for constructed marshes in the Great Bay Estuary to reach reference levels of aboveground production than for constructed marshes further south. In addition, the trajectory model generated shows that biomass values did not reach the reference value (or even the 95% confidence interval value) for 6-7 years (Figure 30b). This is two to three years longer than what has been observed at more southerly sites, indicating that this function takes longer to develop in marshes constructed in the colder New England climate.

The low soil organic matter content in all but one of the constructed marshes we studied was not unexpected (Fig. 28b). Earlier studies have shown that the soil organic matter content of constructed sites is slow to develop. Studies of constructed marshes less than five years of age on the East Coast have shown significantly lower levels of organic matter in constructed marsh soils than in reference site soils (Craft et al. 1988; Moy and Levin 1991). In their study of two constructed salt marshes in North Carolina (22-26 years old), Craft et al. (1999) found the soil organic matter content at one constructed site to be similar to its paired reference site, but at a second constructed site the percent soil organic matter was still significantly less than that of its reference site. The maintenance of adequate soil organic matter content is important for a number of reasons. Organic matter inputs to salt marsh soils help marshes keep pace with rising sea levels and provide an important food source for the marsh detrital food web (Redfield 1972; Nixon 1982). Organic matter reservoirs may also provide nutrients to organisms in the marsh and adjacent waters (Craft et al. 1989). And low soil organic matter content in young constructed salt marsh soils has been correlated with low infaunal diversity (Moy and Levin 1991; Sacco et al. 1994).

The trapping and binding of sediments is an important function of coastal salt marshes, as the rates of deposition and erosion of sediment at a salt marsh site are important factors in determining whether the site is drowning, expanding or being maintained over time (Phillips 1986). 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. Along the Gulf of Maine, sea level has been rising between 0.9 and 3.9 mm/yr., and there is evidence that along parts of Maine's coast, salt marshes are not keeping up with the rate of sea level rise (Kelly 1992). Vertical accretion relies on two sources of sediment; one from inorganic materials borne by 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 (Redfield 1972; Nixon 1982).

In a study of sediment deposition on Louisiana tidal marshes, Reed (1989) found rates of 2.9 $g/m^2/day$ (excluding winter storm events, when sedimentation rates were much higher), which is close to our mean of 2.60 $g/m^2/day$ for reference sites in the Great Bay Estuary. However we observed significantly greater amounts (6.90 $g/m^2/day$) of sediment deposited on all but one of the constructed sites over the same sampling period (Fig. 28c). This was not expected, as previous studies had shown sediment deposition rates to be correlated with plant stem density (Gleason et al. 1979), and the mean percent vegetative cover was much less in the constructed sites (31% +/-11 SE) than in reference sites (58% +/-5 SE). This led us to hypothesize that surface sediments on the constructed sites were being resuspended due to wave action, and that the greater amounts of sediment we observed on constructed site sediment traps were due to the redeposition of this suspended material. Thus, in young constructed sites, our measure of sediment deposition is more related to sediment resuspension, and does not likely reflect accretion, but rather a site's sediment binding ability. To get a better measure of net sediment accumulation over a longer time period in constructed sites, marker horizon methods would be more effective. Feldspar marker horizons have been successfully used to measure 6-12 month sediment accumulation rates in coastal Louisiana marshes (Cahoon and Turner 1989).

A simple measure of the plant diversity of a site is its species richness. While the mean number of species was significantly less for constructed sites than for reference sites (Fig 28d), the range of values for reference sites was high (from 2-13 species per site), and there was considerable overlap between individual constructed and reference sites. The diversity at individual sites as calculated by the Shannon-Weiner index also varied widely among reference sites (Fig. 28e). This high variability among reference sites points out the danger of using species richness or the Shannon-Weiner index as an indicator of plant diversity when comparing a constructed site to a single reference site.

The ordination results give a better picture of how the constructed and reference sites compare in terms of species composition and abundance (Fig. 29). Ordination analysis indicates how similar the plant communities of different sites are with respect to the types of species they contain (composition), as well as the percent cover (abundance) of those species. Clearly, all but the oldest constructed site (site 31, 14 years old) are still quite different from the reference sites in species composition and abundance. While we might not expect a site constructed as a low marsh site to develop a large percent cover of high marsh species, we would expect these sites to be similar to at least some of the natural fringing salt marshes in the Estuary. This goal has not yet been obtained for the five youngest constructed sites, but it has for the 14-year-old site.

Evaluations of constructed salt marsh plant species diversity have been rare for created sites on the East Coast. Havens et al. (1995) reported that the species composition of a five year old created site (excavated upland) in Virginia was similar to that of two nearby reference sites, with *Spartina alterniflora* and *Spartina patens* being the most common species at all three sites. Studies of plant diversity in salt marshes to which tidal flushing has been restored show both high marsh and low marsh species recolonizing after as little as two years. Approximately ten years after tidal flow was restored to an impounded Connecticut salt marsh, Sinicrope et al. (1990) saw *S. alterniflora* increase to 45% cover, compared to <1% cover before restoration; the high marsh species *D. spicata*, *J. gerardii*, *S. patens*, which were not present prior to restoration, comprised 10% of the vegetative cover. Burdick et al. (1997) found that only two years after tidal flow was restored to a New Hampshire salt marsh, *Spartina patens* comprised a large proportion of the site's vegetative cover, making it similar to the high marsh vegetation observed at the reference site. After three years, zonation patterns were beginning to emerge at the restored site, with *S. alterniflora* growing near tidal creeks.

No patterns of plant zonation had formed in the five youngest constructed sites we studied in the Great Bay Estuary. Only the six-year-old site contained the high marsh species *S. patens*, which comprised <1% of the vegetative cover. However the 14-year-old constructed site did contain distinct high marsh and low marsh areas (Table 10). In the reference marshes, the proportion of high marsh vegetation varied from site to site.

Although all natural sites contained some amount of *S. patens, D. spicata* and/or *J. gerardii*, not all sites had distinct bands of high and low marsh vegetation. Also, seven out of the 11 natural sites had more *S. alterniflora* than the three high marsh species combined (Table 10).

C. Functional trajectory models of marsh development

The term "trajectory" has appeared relatively recently in restoration ecology, and has been used to describe the hypothetical path that a restored system takes to reach the level of function observed in healthy, natural ecosystems (Zedler and Callaway 1999). Trajectory models are smooth curves with particular shapes that illustrate patterns of functional development in restored or created sites. They have distinct end-points representing the level of function observed in natural systems. Although the models predict that created and restored site functions will increase to hit an end-point, in reality they may overshoot or never reach the target value (Kentula et al. 1992). The question is, do restored or created systems actually follow these hypothetical trajectories?

Having six constructed salt marshes of different ages all located within the Great Bay Estuary provided us with a unique opportunity to investigate possible patterns of functional development for constructed salt marshes in this part of New England, and to see if the patterns we observed would fit trajectory models. Most of the indicators we selected fit some form of trajectory model for the functions assessed (primary production, soil organic matter accumulation, maintenance of plant diversity, and sediment trapping and binding) (Figures 30-33). The trajectories we developed for each function were smooth curves, and indicator values fit nonlinear models well (all r^2 values greater than 0.9). The exception was the Shannon-Weiner index of plant diversity, which did not increase with the increasing age of constructed marsh sites (Fig. 34). Plant species richness was a better indicator of plant diversity in terms of fitting some reasonable trajectory.

The curves we generated using nonlinear regression are good fits that make sense ecologically, although they are not necessarily the best statistical fit for the data. In all cases, there is some upper (or lower) limit to the curve, and this limit is within the 95% confidence interval of the mean reference site values. Both the aboveground biomass and the soil percent organic matter curves are logistic, increasing slowly at first and then rapidly toward reference values (Figs. 30, 31). It appears to take a few years for a constructed site's vegetation to fill in and become established, after which time there is more source material available to contribute to the soil organic matter content. The increase in soil organic matter content is also related to the rates at which soil Eh values and belowground biomass decomposition decrease. The curve for aboveground biomass is much steeper than that for organic matter, showing that it takes constructed marsh sites longer to build up soil organic matter than it does for them to attain aboveground production values similar to those observed in reference sites. This agrees with what has been reported in other studies of constructed salt marshes along the East Coast (Craft et al. 1999).

Several researchers studying created and restored tidal marshes have attempted to fit constructed site data to trajectories. Simenstad and Thom (1996) tracked a restored tidal wetland in Washington state for several consecutive years, assessing a large number of structural and functional attributes. They found that while some indicators tracked along predictable trajectories over the five-year study period, many did not. Measures of epibenthic and fish taxa richness, fish density, and three indicators of bird use followed reasonable trajectories. Other indicators, including sediment organic matter content, increased slowly toward reference levels (as our trajectory indicates) or not at all. The authors questioned whether this was because the restored marsh was still in an early stage of its development. They pointed out that some indicators might not be good measures of function. However, awareness of a long-term logistic trajectory, as we show with the development of soil organic matter over 14 years, may provide assurance that some constructed marshes can develop predictably.

Zedler and Callaway (1999) reported on four soil and vegetation indicators they had followed for up to ten years in a constructed salt marsh in California. The constructed site and its paired reference site showed high interannual variation, and only soil organic matter content values fit a trajectory model. They warned against making long term predictions using trajectories that are developed from short term observations.

In North Carolina, Craft et al. (1999) monitored two constructed salt marshes over the course of 22-25 years. Although they did not call them trajectories, they developed nonlinear models that fit data they collected at the two constructed sites and at their paired reference sites. At both constructed sites, aboveground biomass values overshot reference values approximately three years after construction, but later dropped to reference site levels. Macro-organic matter (a measure of the living and dead root and rhizome mat) values increased steadily toward reference site values, reaching them much earlier (after 3-5 years) in one site than in the other (after 20+ years). Sediment C:N ratios appeared to follow a linear trajectory, reaching reference site ratios in 10-25 years.

Our study differed from these three in that a number of different-aged constructed salt marshes were compared to a population of reference marshes in the same estuary at a single point in time. The constructed salt marshes we studied did fit trajectory models of functional development for the functions we assessed. The proximity of reference site 30 (estimated to be at most 22 years old) to the trajectory paths in Figures 30-33 lends further support to the models. In addition, the trajectories we generated illustrate once again that while some functions, such as aboveground production, may develop in eight years or less in constructed salt marshes, others will take much longer. Our results indicate that the soil organic matter content of constructed sites will take 15-30 years to reach levels observed in most natural salt marshes in the Great Bay Estuary.

We think that trajectories do have potential to address management questions related to salt marsh construction projects. Tracking the functional development of constructed salt marshes over time and comparing this development to trajectory models should help managers predict whether projects will reach reference levels at some point in time, and may help them determine when this will occur. Also, once trajectories have been developed for constructed salt marshes in a particular area, more effective monitoring protocols can be developed. The best indicators to monitor, as well as the most effective timing and frequency of monitoring can be determined. Trajectories may also provide managers and decision-makers with information they need to establish mitigation goals and ratios. In the Great Bay Estuary, our results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping and binding, and maintenance of plant diversity, monitoring should occur more frequently for the first five years, but should continue for at least 15 years. Also, while the soil organic matter content should be monitored for up to 35 years, few aboveground biomass measurements should be necessary beyond 8-10 years post-construction.

We carefully selected reference sites using PCA, acquired long-term data on marsh development and calculated trajectories to be used for evaluation of salt marsh restoration. Once established for other locations, such trajectories may improve both the planning and monitoring of salt marsh construction.

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APPENDIX

Table A1. Locations of fringing and meadow marsh 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

Table A2. Physical characteristics of fringing and meadow marsh sites. Values are means of nine quadrats per site.

SITE	Distance to edge (m)	Std.Error	Slope (%)	Std.Error	Salinity (ppt)	Std.Error	Elevation (in)[1]	Std.Error	Area (m^2)
FRINGING MARSHES									
SRF	5.24	1.32	10.9	2.5	23.3	2.4	96.8	4.5	1,784
BPF	20.70	4.29	5.1	1.1	30.1	1.0	90.9	9.0	18,951
YRF	6.01	1.72	8.4	1.9	32.6	2.0	111.2	2.6	9,067
ICCF	3.42	0.61	15.6	2.2	29.3	1.0	111.4	8.4	2,155
LHF	10.09	1.41	7.3	1.1	31.5	2.4	115.1	3.3	4,905
mean	9.12	3.09	9.2	3.5	29.4	1.6	105.1	4.7	7,372
MEADOW MARSHES									
BPM	40.78	16.15	1.6	0.5	35.3	1.2	126.0	2.9	173,603
MRM	27.00	7.44	3.7	1.6	31.3	2.3	120.6	3.7	147,146
LRM	53.56	11.83	2.1	0.4	33.8	2.6	129.3	1.0	133,918
DIM	13.67	3.65	3.9	0.8	37.9	1.2	122.2	2.3	169,218
SCM	51.78	10.92	2.7	0.8	31.8	1.9	128.7	1.0	223,320
mean	37.40	7.58	2.8	0.4	34.1	2.7	125.4	3.9	169,441

[1] Elevation values are in inches above mean low tide.

Physical characteristics at fringing and meadow marsh sites. Raw data, collected 1997.

Site	Quad	Distance to Edge (m)	Slope (%)	Salinity (ppt)	Elevation
SRF	1	4.4	9.58	25	93.8625
SRF	2	10.7	3.23	19	113.7375
SRF	3	11.1	2.90	11	109.4875
SRF	4	4.9	1.39	25	100.8625
SRF	5	2	9.50	27	90.3625
SRF	6	2.6	18.40	27	85.2375
SRF	7	8.8	12.32		113.8625
SRF	8	1.4	20.00		88.1125
SRF	9	1.3	20.90	29	75.8625
BPF	1	33.7	2.96	27	135.6125
BPF	2	10.3	4.95	25	68.7375
BPF	3	20.5	4.82	33	102.4875
BPF	4	24.9	3.63	30	104.3625
BPF	5	9.7	10.10	33	86.4875
BPF	6	33.5	0.38	31	101.2375
BPF	7	12.5	4.17	33	61.1125
BPF	8	2.2	4.68	27	50.1125
BPF	9	39	10.63	32	108.1125
YRF	1	2.1	17.44		106.175
YRF	2	1	8.97		94.675
YRF	3	6.2	5.75	42	111.675
YRF	4	12.2	0.96	36	111.425
YRF	5	14.1	12.80	30	118.8
YRF	6	10.2	6.41	30	111.175
YRF	7	0.5	15.52	33	111.8
YRF	8	1.4	5.84	25	113.05
YRF	9	6.4	1.86	32	122.175
LHF	1	8.5	10.96	28	103.55
LHF	2	6.3	5.86	29	98.425
LHF	3	9.1	6.22		117.175
LHF	4	5.7	10.30	26	112.3
LHF	5	18.9	7.00	40	123.675
LHF	6	12.2	6.06	38	119.8
LHF	7	12.1	0.22		131.05
LHF	8	6.1	9.34		111.175
LHF	9	11.9	9.66	28	119.05
ICCF	1	3.3	26.47	26	107.05
ICCF	2	3.8	7.83	28	110.3
ICCF	3	2.2	16.67	31	102.55
ICCF	4	3.3	8.48	32	115.3
ICCF	5	7.1	16.84		127.425
ICCF	6	0.8	10.75	28	101.05
ICCF	7	4.6	20.45		120.3
ICCF	8	1.8	11.41	31	107.925
ICCF	9	3.9	21.73		111.05
UNEM	1	6	0.70	30	125.55
UNEM	2	4	0.83	30	109.3
UNEM	3	3	5.69	37	115.55
UNEM	4	5	0.96	36	121.925
UNEM	5	34	1.42	37	133.05
UNEM	6	20	1.76	39	131.3

Physical characteristics at fringing and meadow marsh sites. Raw data, collected 1997.

Site	Quad	Distance to Edge (m)	Slope (%)	Salinity (ppt)	Elevation
UNEM	7	53	0.59	36	134.55
UNEM	8	120	1.78	40	129.175
UNEM	9	122	0.41	35	133.425
MRM	1	56	1.13	20	117.925
MRM	2	3	8.73	32	102.425
MRM	3	3	0.00	36	114.05
MRM	4	4	3.69	30	108.3
MRM	5	50	1.50	20	125.925
MRM	6	41	0.30	37	123.55
MRM	7	19	1.19	35	124.3
MRM	8	17	14.71	35	136.05
MRM	9	51	2.48	37	132.925
LRM	1	45	2.54	42	127.363
LRM	2	54	1.38	30	131.113
LRM	3	97	2.36	16	132.238
LRM	4	24	3.10	36	128.363
LRM	5	22	0.75	35	129.613
LRM	6	49	0.59	35	130.238
LRM	7	84	4.42	37	131.363
LRM	8	105	1.47	42	130.988
LRM	9	2	2.63	31	122.363
DIM	1	36	2.34	37	129.3
DIM	2	13	1.84	30	132.175
DIM	3	12	4.40	42	124.925
DIM	4	5	2.77	41	116.925
DIM	5	26	6.22	41	128.8
DIM	6	3	4.25	36	115.925
DIM	7	4	7.55	38	112.175
DIM	8	15	5.21	40	117.925
DIM	9	9	0.47	36	121.55
SCM	1	53	3.06	28	127.425
SCM	2	94	0.70	26	129.8
SCM	3	36	1.11	31	132.925
SCM	4	111	2.25	35	127.175
SCM	5	52	2.33	24	125.175
SCM	6	52	2.38	40	130.175
SCM	7	5	8.81	40	124.3
SCM	8	36	2.37	33	128.175
SCM	9	27	1.29	29	133.3

Table A3. Correlations between physical characteristics and indicators of salt marsh functions.
Site level correlations are based on site mean values (mean of nine quadrats at each site).
Quadrat level correlations are based on individual quadrat values.

Indicator of marsh function	Physical characteristic	Marsh sites incuded	Site level correlation	Quadrat level correlation
Aboveground biomass	Surface slope (%)	Fringing	0.935	0.384
		Meadow	0.336	0.310
Belowground biomass	Surface slope (%)	Fringing	0.939	0.020
		Meadow	0.083	0.267
Belowground biomass	Elevation	Fringing and Meadow	0.462	0.210
Soil organic matter (%)	Elevation	Fringing and Meadow	0.801	0.619
Plant species richness	Surface slope (%)	Fringing and Meadow	-0.726	-
Plant species richness	Elevation	Fringing and Meadow	0.46	-
Plant species density	Surface slope (%)	Fringing and Meadow	-0.806	-
Plant species density	Elevation	Fringing and Meadow	0.792	-
Sediment deposited - Traps randomly distributed	Elevation	Fringing and Meadow	-0.721	-0.635
Sediment deposited - Traps 1m from marsh edge	Elevation	Fringing and Meadow	-0.732	-0.427
Sediment deposited - Traps randomly distributed	Suspended sediment	Fringing and Meadow	0.069	-0.051
		Fringing	0.982	0.456
		Meadow	-0.481	-0.233
Sediment deposited - Traps 1m from marsh edge	Suspended sediment	Fringing and Meadow	0.269	0.101
		Fringing	0.999	0.693
		Meadow	0.193	0.097

Table A4. Aboveground biomass, belowground biomass and percent soil organic matter values for fringing and meadow marsh sites. Values are means of nine samples per site.

SITE	MARSH TYPE	Aboveground Biomass (g/m^2)	Belowground Biomass (g/m^2)	% Soil Organic Matter
SR F	Fringing	329.4	1436.4	10.9
BP F	Fringing	193.7	958.4	7.4
YR F	Fringing	290.5	1461.6	16.6
LH F	Fringing	160.7	982.5	4.5
ICC F	Fringing	451.5	2055.0	21.8
BP M	Meadow	249.1	1285.9	43.1
MR M	Meadow	358.2	1931.6	40.9
LR M	Meadow	279.9	1582.5	32.9
DI M	Meadow	239.3	1366.7	38.8
SC M	Meadow	244.6	3253.3	54.3

Aboveground and belowground biomass values at fringing and meadow salt marsh sites. Raw data collected summer 1997.

Site	Quad	Aboveground Dry Wt (g/m^2)	Belowground Dry Wt (g/m^2)
SRF	1	509.424	1080.68
SRF	2	39.648	1426.50
SRF	3	74.448	155.23
SRF	4	229.04	2033.65
SRF	5	269.12	1760.53
SRF	6	575.28	840.97
SRF	7	199.6	683.78
SRF	8	398.848	3035.73
SRF	9	669.456	1910.84
BPF	1	430.944	2230.13
BPF	2	102.816	864.55
BPF	3	170.032	1002.09
BPF	4	228.224	265.26
BPF	5	122.032	1974.70
BPF	6	280.4	687.71
BPF	7	89.84	481.39
BPF	8	34.864	0.00
BPF	9	283.76	1119.98
YRF	1	61.328	677.88
YRF	2	247.36	1650.50
YRF	3	164.416	2839.25
YRF	4	354.08	559.99
YRF	5	288.08	1316.47
YRF	6	420.08	88.42
YRF	7	340.16	1188.75
YRF	8	436.624	1837.16
YRF	9	302.72	2996.44
LHF	1	6.288	0.00
LHF	2	72.048	209.26
LHF	3	239.28	2188.87
LHF	4	140.368	1121.94
LHF	5	86	610.09
LHF	6	137.36	1610.22
LHF	7	277.84	86.45
LHF	8	342.56	2647.67
LHF	9	144.96	368.41
ICCF	1	793.184	1786.07
ICCF	2	380.656	2061.15
ICCF	3	811.312	5607.76
ICCF	4	237.568	1477.59
ICCF	5	83.072	93.33
ICCF	6	888.976	2958.16
ICCF	7	291.92	2307.75
ICCF	8	460.336	2205.57
ICCF	9	116.288	0.00
UNEM	1	136.88	2377.50
UNEM	2	214.224	658.23
UNEM	3	373.248	844.90

Aboveground and belowground biomass values at fringing and meadow salt marsh sites. Raw data collected summer 1997.

Site	Quad	Aboveground Dry Wt (g/m^2)	Belowground Dry Wt (g/m^2)
UNEM	4	529.44	2092.59
UNEM	5	319.12	1277.17
UNEM	6	282.144	1198.57
UNEM	7	221.84	1994.35
UNEM	8	65.168	58.95
UNEM	9	99.456	1070.86
MRM	1	314.96	1190.71
MRM	2	551.04	1760.53
MRM	3	487.344	1037.45
MRM	4	450.96	306.52
MRM	5	249.6	1264.40
MRM	6	247.84	1861.72
MRM	7	311.104	2487.53
MRM	8	398.224	4260.83
MRM	9	213.04	3214.54
LRM	1	136.8	1293.87
LRM	2	180.352	0.00
LRM	3	404.336	1551.27
LRM	4	161.248	763.35
LRM	5	254	1062.02
LRM	6	168.448	2630.97
LRM	7	443.28	2417.78
LRM	8	341.056	3249.90
LRM	9	429.504	1273.24
DIM	1	73.36	765.32
DIM	2	50.48	250.52
DIM	3	254.176	2539.60
DIM	4	323.04	1352.82
DIM	5	278.192	810.51
DIM	6	450.4	1653.44
DIM	7	310.48	2584.79
DIM	8	255.408	1810.63
DIM	9	157.76	532.48
SCM	1	336.512	3981.82
SCM	2	342.064	1231.98
SCM	3	239.76	4997.66
SCM	4	206.96	2184.94
SCM	5	183.44	6273.85
SCM	6	250	2645.71
SCM	7	192.8	3877.68
SCM	8	346.032	839.00
SCM	9	103.552	3246.96

Soil organic matter in fringing and meadow salt marshes. Raw data collected summer 1997.

SITE	Quadrat	%OM	Grams organic matter per m^2
BPF	Q1		
BPF	Q2	2.6	3661
BPF	Q3	9.8	6818
BPF	Q4	7.9	6336
BPF	Q5	3.4	4355
BPF	Q6	9.7	8026
BPF	Q7	1.4	2094
BPF	Q8	*	*
BPF	Q9	17.3	9700
DIM	Q1	48.8	9931
DIM	Q2	72.5	14952
DIM	Q3	*	*
DIM	Q4	21.8	9142
DIM	Q5	47.5	10135
DIM	Q6	18.8	8866
DIM	Q7	26.3	7929
DIM	Q8	38.2	9441
DIM	Q9	36.6	8960
ICCF	Q1	17.1	8039
ICCF	Q2	19.4	9012
ICCF	Q3	19.6	7790
ICCF	Q4	35.7	7908
ICCF	Q5	9.2	7365
ICCF	Q6	*	*
ICCF	Q7	24.2	8813
ICCF	Q8	27.3	9175
ICCF	Q9	*	*
LHF	Q1	4.4	5201
LHF	Q2	*	*
LHF	Q3	1.3	1663
LHF	Q4	7.4	7030
LHF	Q5	6.1	7026
LHF	Q6	8.6	7969
LHF	Q7	0.9	1319
LHF	Q8	2.5	3246
LHF	Q9	*	*
LRM	Q1	4.8	5389
LRM	Q2	*	*
LRM	Q3	*	*
LRM	Q4	*	*
LRM	Q5	*	*
LRM	Q6	33.7	7737
LRM	Q7	53.8	10620
LRM	Q8	55.1	10812
LRM	Q9	17.0	9009
MRM	Q1	69.3	9649
MRM	Q2	26.5	11276
MRM	Q3	15.5	8963
MRM	Q4	18.0	10702
MRM	Q5	72.1	15590

Soil organic matter in fringing and meadow salt marshes. Raw data collected summer 1997.

SITE	Quadrat	%OM	Grams organic matter per m^2
MRM	Q6	47.5	10610
MRM	Q7	50.0	8674
MRM	Q8	13.0	10316
MRM	Q9	56.4	5360
SCM	Q1	*	*
SCM	Q2	62.9	12791
SCM	Q3	63.6	11247
SCM	Q4	49.8	11832
SCM	Q5	53.7	11547
SCM	Q6	52.8	11988
SCM	Q7	*	*
SCM	Q8	32.7	10245
SCM	Q9	64.5	11376
UNEF	Q1	9.8	9603
UNEF	Q2	4.3	5511
UNEF	Q3	6.0	3945
UNEF	Q4	18.2	9347
UNEF	Q5	10.9	7114
UNEF	Q6	15.3	11503
UNEF	Q7	5.3	2609
UNEF	Q8	17.2	6978
UNEF	Q9	*	*
UNEM	Q1	23.3	10136
UNEM	Q2	20.5	8179
UNEM	Q3	*	*
UNEM	Q3	22.5	8372
UNEM	Q4	*	*
UNEM	Q5	52.0	9177
UNEM	Q6	51.3	8281
UNEM	Q7	56.9	10139
UNEM	Q8	56.5	8401
UNEM	Q9	61.7	10343
YRF	Q1	4.6	5435
YRF	Q2	4.9	5136
YRF	Q3	6.7	6237
YRF	Q4	14.1	8612
YRF	Q5	24.2	9036
YRF	Q6	26.9	8914
YRF	Q7	26.8	7264
YRF	Q8	27.8	8575
YRF	Q9	12.9	7907

* no data

Table A5. Percent covers of plant species on fringing and meadow marsh sites. Numbers are means of ten 1m² quadrats per site. (Numbers in parentheses are means of thirty 10m2 quadrats per site.)

SITE	TYPE	*Agalinis maritima*	*Agropyron pungens*	*Atriplex patula*	*Carex paleacea*	*Distichlis spicata*	*Festuca rubra*	*Glaux maritima*	*Juncus gerardii*	*Limonim nashii*	*Potentilla anserina*	*Plantago maritima*	*Puccinellia maritima*	*Spartina alterniflora*	*Scirpus maritimus*	*Scirpus pungens*	*Salicornia europaea*	*Sueda maritima*	*Spartina patens*	*Spergularia marina*	*Solidago sempervirens*	*Triglochin maritimum*
BPM	Meadow			(<1)		2 (1)		4 (2)	16 (8)	1 (1)		4 (4)	(2)	41 (22)			<1 (1)	(<1)	3 (31)			1 (4)
LRM	Meadow			<1 (<1)		3.7	(<1)	(1)	(6)	1 (1)		7 (8)	2 (2)	29 (19)			1 (1)	(<1)	52 (44)		(<1)	1 (1)
DIM	Meadow	(<1)		<1 (<1)		<1 (3)	(<1)	(<1)	(1)	2 (1)		11 (12)	1 (1)	19 (12)			1 (1)	<1 (<1)	48 (44)			3 (6)
SCM	Meadow	(<1)		1 (<1)		20 (14)		<1 (<1)	10 (12)	<1 (1)		1 (4)	2 (2)	2 (9)	(<1)	(<1)	<1 (<1)	(<1)	48 (42)		(1)	4 (3)
MRM	Meadow	<1 (<1)		<1 (<1)	<1 (<1)	(2)	(<1)	8 (3)	<1 (8)	<1 (1)	<1 (<1)	1 (2)	1 (3)	4 (16)	(<1)		1 (1)	(1)	61 (43)	(<1)	<1 (<1)	14 (8)
YRF	Fringing								15	<1			5	20			1	1	23			
SCF	Fringing				<1			3	10	<1		1		46					5		<1	3
BPF	Fringing		<1	<1				<1	7	1			2	23			2	<1	24	2	2	
LHF	Fringing			<1						<1			2	42			1	<1	20			
ICCF	Fringing									<1		5	1	44			2	<1	16	<1	<1	

Table A6. Plant community characteristics of fringing and meadow marsh sites. Meadow marsh values in parentheses are based on thirty quadrats sampled per site; all other values are based on ten quadrats sampled per site.

SITE	TYPE	H'	E	Percent cover *S. alterniflora*	Percent cover PM,JG,SP,DS[1]	Species density (#species/m^2)
BPM	meadow	0.572	0.600	40 (22)	20 (42)	2.9 (4.4)
LRM	meadow	0.473	0.523	29 (19)	54 (56)	4.5 (5.1)
DIM	meadow	0.561	0.561	19 (12)	49 (48)	5.4 (5.4)
SCM	meadow	0.585	0.562	2 (9)	78 (69)	4.0 (4.7)
MRM	meadow	0.495	0.432	4 (16)	62 (55)	5.5 (4.6)
YRF	fringing	0.613	0.726	20	43	2.9
SRF	fringing	0.495	0.519	46	15	2.8
BPF	fringing	0.665	0.616	22	33	2.9
LHF	fringing	0.367	0.434	42	21	2.7
ICCF	fringing	0.469	0.492	44	17	2.9

[1] PM = *Puccinellia maritima* , JG = *Juncus gerardii* , SP = *Spartina patens*, DS = *Distichlis spicata*

Table A7. Sediment deposition on fringing marshes, meadow marshes and areas where no marsh was present. All 'random' and '1m from edge' values are means for five traps, and all 'no marsh areas' are means for three traps.

SITE	Trap location	MARSH TYPE	Sediment deposited ($g/m^2/day$)	Suspended sediment (g/l)	%SLOPE	Ei (in)	Plant % cover/m^2	Distance to Edge (m)
BP F	random	F	4.31	0.226	4.9	84.0	57.4	17.3
ICC F	random	F	1.48	0.037	15.2	110.3	75.0	3.2
LH F	random	F	0.71	0.011	8.6	110.1	53.6	8.3
SR F	random	F	0.44	0.020	12.6	98.1	84.0	5.7
YR F	random	F	1.07	0.017	9.0	112.1	85.8	4.7
DI M	random	M	0.44	0.108	3.8	126.2	79.8	18.0
LR M	random	M	0.20	0.229	1.5	130.1	95.2	63.6
MR M	random	M	0.63	0.069	4.3	122.4	91.0	33.6
SC M	random	M	0.32	0.436	3.8	126.9	94.4	54.6
BP M	random	M	1.51	0.107	1.0	126.5	84.0	37.0
BP F	1m in from edge	F	95.90	0.226	*	56.1	26.0	1.0
ICC F	1m in from edge	F	8.33	0.037	*	94.2	62.4	1.0
LH F	1m in from edge	F	0.88	0.011	*	86.9	56.0	1.0
SR F	1m in from edge	F	0.64	0.020	*	77.1	52.5	1.0
YRF	1m in from edge	F	2.26	0.017	*	103.7	77.0	1.0
DI M	1m in from edge	M	0.77	0.108	*	106.3	68.0	1.0
LR M	1m in from edge	M	3.37	0.229	*	116.6	92.4	1.0
MR M	1m in from edge	M	5.56	0.069	*	104.6	77.0	1.0
SC M	1m in from edge	M	3.99	0.436	*	103.3	78.0	1.0
BP M	1m in from edge	M	2.04	0.107	*	121.4	91.0	1.0
BPX	no marsh area	X	16.44	*	*	63.4	0	n/a
ICCX	no marsh area	X	1.96	*	*	90.6	0	n/a
LHX	no marsh area	X	0.97	*	*	89.6	0	n/a
SRX	no marsh area	X	1.21	*	*	89.5	0	n/a
YRX	no marsh area	X	0.62	*	*	106.8	0	n/a

Sediment data from fringing, meadow and 'no marsh' sites.
Raw data collected 1997.

SITE*	QUADRAT	A/B**	Sed/area/time (g/m^2/day)
BPF	2	A	11.04
BPF	2	B	10.21
BPF	3	A	1.71
BPF	3	B	300.12
BPF	5	A	0.81
BPF	5	B	8.31
BPF	6	A	0.92
BPF	6	B	3.42
BPF	7	A	7.07
BPF	7	B	157.43
DIM	1	A	0.07
DIM	1	B	1847.89
DIM	2	A	1.03
DIM	2	B	0.80
DIM	3	A	0.43
DIM	3	B	0.48
DIM	5	A	0.03
DIM	5	B	0.89
DIM	6	A	0.65
DIM	6	B	0.92
LHF	1	A	0.77
LHF	1	B	0.67
LHF	2	A	1.16
LHF	2	B	1.11
LHF	3	A	1.17
LHF	3	B	0.64
LHF	4	A	0.29
LHF	4	B	1.65
LHF	9	A	0.17
LHF	9	B	0.36
LRM	1	A	0.36
LRM	1	B	10.39
LRM	3	A	0.00
LRM	3	B	0.78
LRM	5	A	0.00
LRM	5	B	1.02
LRM	6	A	-0.04
LRM	6	B	2.33
LRM	8	A	0.70
LRM	8	B	2.31
MRM	1	A	0.24
MRM	1	B	11.80
MRM	4	A	1.53
MRM	4	B	8.96
MRM	5	A	-0.01
MRM	5	B	2.40
MRM	6	A	0.66
MRM	6	B	2.57
MRM	8	A	0.72
MRM	8	B	2.07
ICCF	1	A	1.81
ICCF	1	B	31.82
ICCF	2	A	2.22
ICCF	2	B	5.12
ICCF	4	A	0.98
ICCF	4	B	1.57
ICCF	8	A	2.05
ICCF	8	B	1.26
ICCF	9	A	0.34
ICCF	9	B	1.89
SCM	1	A	0.22
SCM	1	B	7.89

Sediment data from fringing, meadow and 'no marsh' sites.
Raw data collected 1997.

SITE*	QUADRAT	A/B**	Sed/area/time (g/m^2/day)
SCM	4	A	0.18
SCM	4	B	2.23
SCM	5	A	0.20
SCM	5	B	4.46
SCM	6	A	0.41
SCM	6	B	2.09
SCM	7	A	0.58
SCM	7	B	3.28
SRF	1	A	0.49
SRF	1	B	1.34
SRF	3	A	0.56
SRF	3	B	0.48
SRF	6	A	0.39
SRF	6	B	0.20
SRF	7	A	0.30
SRF	7	B	0.26
SRF	8	A	0.44
SRF	8	B	0.94
UNEM	3	A	3.49
UNEM	3	B	7.52
UNEM	5	A	0.33
UNEM	5	B	1.53
UNEM	6	A	1.00
UNEM	6	B	0.34
UNEM	7	A	1.24
UNEM	7	B	0.58
UNEM	9	A	1.49
UNEM	9	B	0.22
YRF	2	A	2.07
YRF	2	B	5.71
YRF	5	A	0.30
YRF	5	B	1.69
YRF	7	A	0.58
YRF	7	B	2.34
YRF	8	A	0.77
YRF	8	B	0.79
YRF	9	A	1.62
YRF	9	B	0.78
BPFX	x	1	3.64
BPFX	x	2	43.20
BPFX	x	3	2.47
LHFX	x	1	1.28
LHFX	x	2	0.67
LHFX	x	3	
ICCFX	x	1	1.24
ICCFX	x	2	3.92
ICCFX	x	3	0.73
ICCFX	x	1	
SRFX	x	2	1.36
SRFX	x	3	1.06
YRFX	x	1	
YRFX	x	2	0.42
YRFX	x	3	0.81

* Letters at end of site names designate site type: fringing, meadow or no marsh.
** A traps were randomly disributed; B traps were 1m from the marsh edge.

Table A8. Percent reduction in the height of the tallest wave as it traveled 5m or 7m into fringing marsh, meadow marsh and no marsh sites. Values are means of three 'takes' per transect.

SITE	MARSH TYPE[1]	Transect	% wave ht. reduction		Mean % wave reduction/site	
			5m	7m	5m	7m
BPF	F	1	38.9	46.9	42.0	52.1
BPF	F	2	40.4	56.5		
BPF	F	3	46.9	52.7		
SRF	F	1	42.6	55.7	35.4	49.9
SRF	F	2	23.5	*		
SRF	F	3	40.0	44.1		
YRF	F	1	55.1	79.7	65.1	85.1
YRF	F	2	75.0	90.5		
YRF	F	3	*	*		
DIM	M	1	88.4	94.7	67.0	69.1
DIM	M	2	36.6	33.6		
DIM	M	3	75.9	79.1		
MRM	M	1	51.3	79.7	42.4	70.2
MRM	M	2	21.6	46.1		
MRM	M	3	54.4	84.8		
BPM	M	1	38.9	41.7	52.9	52.2
BPM	M	2	100.0	99.2		
BPM	M	3	19.9	15.7		
BP X	X	1	33.5	50.1	33.8	33.5
BP X	X	2	35.2	39.8		
BP X	X	3	32.6	10.5		
SR X	X	1	38.1	16.3	29.0	43.8
SR X	X	2	22.0	49.8		
SR X	X	3	26.8	65.3		
YR X	X	1	24.6	16.6	30.7	22.2
YR X	X	2	18.0	*		
YR X	X	3	49.4	27.7		

[1] F = fringing, M = Meadow, X = 'no marsh'

Table A9. Percent reduction in the average height of the tallest wave and the two waves following it as they traveled 5m or 7m into fringing marsh, meadow marsh and no marsh sites. Values are means of three 'takes' per transect.

SITE	MARSH TYPE[1]	Transect	% wave ht. reduction		Mean % wave reduction/site	
			5m	7m	5m	7m
BPF	F	1	15.89	26.29	21.84	38.33
BPF	F	2	15.28	39.04		
BPF	F	3	34.33	49.66		
SRF	F	1	44.00	47.25	34.25	47.25
SRF	F	2	29.13	*		
SRF	F	3	29.63	*		
YRF	F	1	48.05	71.77	60.93	79.18
YRF	F	2	73.82	86.58		
YRF	F	3	*	*		
DIM	M	1	86.55	92.93	62.86	63.14
DIM	M	2	29.41	20.53		
DIM	M	3	72.61	75.96		
MRM	M	1	52.28	73.37	37.43	56.20
MRM	M	2	14.62	24.53		
MRM	M	3	45.39	70.71		
BPM	M	1	27.30	27.96	50.11	37.98
BPM	M	2	100.00	99.50		
BPM	M	3	23.04	-13.51		
BP X	X	1	18.71	29.16	18.01	23.36
BP X	X	2	9.65	34.73		
BP X	X	3	25.67	6.20		
SR X	X	1	30.93	-3.66	33.73	31.29
SR X	X	2	35.74	41.48		
SR X	X	3	34.53	56.04		
YR X	X	1	16.48	30.42	35.98	29.71
YR X	X	2	56.90	*		
YR X	X	3	34.58	29.01		

[1] F = fringing, M = Meadow, X = 'no marsh'

Time 0 measurements (May 29, 1998) - Slope/orientation experiment

PLANT #	LEAF #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	TOTAL# LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
16	1	16.5	0.8	8	4	11.5		
	2	10.5	0.4					
	3	13.2	0.7					
	4	8	0.6					
29	1	10	0.5	10.5	2	10		
	2	3.8	0.4					
11	1	17	0.8	7.5	4	22		
	2	15.8	0.9					
	3	10.3	0.7					
	4	11	0.4					
20	1	13.5	0.7	9	4	13.2	0.205	0.187
	2	11.5	0.5					
	3	8.5	0.6					
	4W	4.8	0.4					
26	1	14.5	0.6					
	2	17.5	0.9	12	4	4		
	3	13.5	0.8					
	4	10	0.8					
12	1	13.5	0.8	10.5	5	6.2		
	2	17.5	0.9					
	3	12	0.6					
	4	8.5	0.6					
	5W	4	0.5					
37	1	16.5	0.7	9.5	6	8.5		
	2	12	0.5					
	3	14	0.8					
	4	8.3	0.7					
	5W	4	0.6					
21	1	13	0.7	11	4	8.5		
	2	10.4	0.7					
	3	16	0.7					
	4	7.5	0.5					
14	1	14	0.8	11	4	11.5		
	2	11.5	0.6					
	3	9.5	0.7					
	4	5.5	0.5					
27	1	18	0.8	9.5	5	7		
	2	15.2	0.8					
	3	9.5	0.4					
	4	10.5	0.7					
	5	5.5	0.6					
4	1	8	0.5	6.8	3	6		
	2	13.7	0.7					
	3	13.2	0.6					
38	1	5.4	0.6	9.1	5	7		
	2	10.9	0.8					
	3	16.8	0.9					
	4	22.1	1					
	5	16.4	0.7					
5	1	12.7	0.7	9.9	4	7.6		
	2	6.1	0.5					
	3	15.6	0.7					
	4W	2.8	0.4					
28	1	11.6	0.6	6.5	5	3.7		
	2	5.7	0.4					
	3	17.3	0.7					
	4	11.4	0.4					
	5W	4.4	0.4					
24	1	3.2	0.4	6.9	4	5.1	0.235	0.116
	2	8	0.6					
	3	15.2	0.8					
	4	12.8	0.6					
31B	1	19.5	0.8	16.5	4	2.5		
	2	18.5	0.7					
	3	12.5	1					
	4	6	0.6					
19	1	17.5	0.9	14	4	8		
	2	14.5	0.7					
	3	11.5	0.8					
	4	7	0.6					
22	1	17	0.7	7.5	4	7.5	0.24	0.132
	2	11	0.4					
	3	15.8	0.6					
	4W	6.5	0.4					
23	1	15	0.8	13.5	5	18		
	2	14	0.8					
	3	20	0.9					
	4	9	0.7					
	5W	4.5	0.6					
25	1	18.5	0.9	12	5	13		
	2	14	0.8					
	3	12	0.8					
	4	6	0.7					
	5W	3.5	0.4					
9	1	21	0.8	13.5	5	14		
	2	18.5	0.8					
	3	14	0.8					
	4	9.5	0.8					
	5	4	0.6					
13	1	18	0.9	10.5	4	7		
	2	14.5	0.8					
	3	13	0.6					
	4W	9	0.7					
10	1	13.5	0.7	13	3	8.5		
	2	13.5	0.7					
	3	9.5	0.6					

Time 0 measurements (May 29, 1998) - Slope/orientation experiment

PLANT #	LEAF #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	TOTAL # LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
7	1	19	0.8	10.5	5	11		
	2	16.5	0.9					
	3	9.6	0.7					
	4	13.5	0.5					
	5W	4.5	0.7					
17	1	19	0.9	11.5	5	8		
	2	17.5	0.9					
	3	13	0.5					
	4	13.5	0.8					
	5	6.8	0.6					
30	1	19.5	0.9	15	5	8		
	2	14.5	0.5					
	3	15.5	1					
	4	11	0.9					
	5	6	0.8					
15	1	18	0.8	10	5	8.5		
	2	15.3	0.8					
	3	12	0.5					
	4	10.5	0.6					
	5W	5.1	0.4					
63	1	8.7	0.7	10.2	3	8.1		
	2	14.7	0.9					
	3	16.2	0.8					
65	1	6.4	0.7	6.9	5	23.5		
	2	14.2	1.1					
	3	9.8	0.8					
	4	17.8	1					
	5	12.9	0.6					
31A	1	14.1	0.7	7	4	9		
	2	7.1	0.4					
	3	18.9	0.9					
	4	12.6	0.6					
3	1	18.1	0.8	8.1	4	8.4		
	2	19.7	0.9					
	3	8	0.6					
	4	14.5	0.7					
18	1	10.7	0.8	10.8	5	4.9		
	2	5.4	0.6					
	3	16.5	0.9					
	4	17.2	1					
	5W	2.3	0.5					
6	1	10.9	0.7	5.9	5	3.4		
	2	6.5	0.6					
	3	11.9	0.6					
	4	16.5	0.8					
	5W	4.9	0.4					
66B DOUBLE	1	14	0.8	10.5	4	12		
	2	13.5	0.7					
	3	8.6	0.6					
	4W	3.2	0.5					
51	1	16	0.9	7	6	2.6		
	2	14	0.7					
	3	11	0.8					
	4	8	0.7					
	5	8	0.4					
46	1	20	0.8	14.5	6	6.5		
	2	14.2	0.8					
	3	15.4	0.7					
	4	8.5	0.5					
	5W	5.5	0.4					
62	1	20	0.9	16.5	5	7		
	2	14	0.8					
	3	18.5	0.8					
	4	9.1	0.6					
	5W	5.2	0.5					
52	1	18	0.9	14	4	11		
	2	15	0.8					
	3	11.5	0.8					
	4	6	0.6					
43	1	20	0.9	15	5	8		
	2	17.5	0.8					
	3	12.5	0.8					
	4	6.1	0.5					
	5W	5.2	0.5					
34	1	13.9	0.8	8.4	3	2.6	0.265	0.104
	2	8.5	0.7					
	3	13.6	0.7					
	4W	4.8	0.4					
39	1	10.3	0.7	8.6	4	12.9		
	2	5.6	0.6					
	3	18.7	0.9					
	4	15	0.7					
32	1	13.2	0.7	5.8	4	9.5		
	2	16.1	0.8					
	3	9.5	0.6					
	4	11.5	0.6					
44	1	7	0.6	5.9	4	7.6		
	2	11.3	0.7					
	3	17	0.8					
	4	13.3	0.6					
54	1	11.7	0.6	11.2	3	9.1		
	2	16.8	0.8					
	3	17.1	0.8					
	4W	6.5	0.5					
45	1	4.1	0.5	9.3	4	15.7		
	2	16.6	0.9					

Time 0 measurements (May 29, 1998) - Slope/orientation experiment

PLANT #	LEAF #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	TOTAL# LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
	3	15	0.8					
	4	8.9	0.7					
40	1	21	0.9	14.5	6	5		
	2	18.2	1					
	3	12.9	1					
	4	6.5	0.7					
	5W	5.2	0.6					
	6	14.7	0.4					
66	1	16.8	0.8	10.5	4	8.5		
	2	13.5	0.6					
	3	12.2	0.8					
	4	6.5	0.5					
53	1	19	1	18	4	10.5		
	2	18.5	0.8					
	3	14	0.8					
	4	8.5	0.5					
33	1	20	0.9	12.5	5	10		
	2	20.2	0.9					
	3	14	0.5					
	4	12.8	0.9					
	5	6.4	0.6					
36	1	17.2	0.8	13.6	4	8		
	2	15	0.7					
	3	13	0.9					
	4	8.2	0.7					
42	1	16	0.7	15	4	3.5	0.358	0.123
	2	18	0.8					
	3	10.6	0.6					
	4	4.4	0.4					
1	1	16.6	0.6	15.6	4	3.2	0.221	0.527
	2	13.2	0.8					
	3	6.9	0.7					
	4W	6	0.6					
2	1	11.5	0.7	13.5	4	11		
	2	14.6	0.7					
	3	7	0.8					
	4W	3.2	0.5					
8	1	16.7	0.8	15.2	4	8.5		
	2	16	0.7					
	3	11	0.8					
	4W	6	0.4					
61	1	22	1	15	4	15		
	2	17	0.8					
	3	14.2	0.9					
	4	6.5	0.7					
57	1	18.4	0.9	16.5	4	16		
	2	18	0.8					
	3	11.4	0.8					
	4	4.8	0.7					
49	1	22	1	19	5	6		
	2	19	0.7					
	3	14.5	0.8					
	4	8.5	0.7					
	5W	5	0.7					
47	1	21.5	0.9	16	5	13		
	2	16	0.8					
	3	15	1					
	4	9.5	0.7					
	5	4.2	0.6					
48	1	19	0.9	14	5	2.5		
	2	16	0.7					
	3	10.5	0.9					
	4	5.5	0.8					
	5	5	0.6					
58	1	18.5	0.8	13	4	7		
	2	14	0.6					
	3	11.1	0.4					
	4	6.1	0.5					
45	1	15.6	0.9	15	4	15.2		
	2	15	0.7					
	3	9	0.7					
	4	4.1	0.5					
60	1	18.5	0.7	11	5	4.8		
	2	15.2	0.9					
	3	18	0.8					
	4	12	0.5					
	5	4.2	0.6					
59	1	16.2	0.8	6.2	5	2.5		
	2	5.1	0.5					
	3	10.1	0.6					
	4	13	0.6					
	5W	5.4	0.3					
64	1	15.9	0.7	7.3	4	8.1		
	2	21.5	0.8					
	3	14.8	0.6					
	4W	4.4	0.6					
41	1	8.6	0.6	8.8	5	10.2		
	2	3.3	0.5					
	3	13.4	0.7					
	4W	1.6	0.4					
	5W	1.3	0.4					
56	1	10.8	0.8	8.6	7	15.6		
	2	16.5	1					
	3	21.1	1					
	4	15.2	0.7					
	5W	2.5	0.2					

Time 0 measurements (May 28, 1998) - Slope/orientation experiment

PLANT #	LEAF #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	TOTAL # LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
	6W	4.6	0.8					
	7W	4.9	0.7					
55A	1	14.2	0.8	8.3	4	10.8		
DOUBLE	2	8.5	0.6					
	3	13.5	0.7					
	4W	3.3	0.5					
66	1	13.1	0.8	13.1	4	14.6	0.417	0.378
	2	6.1	0.4					
	3	20.6	0.9					
	4	19.4	0.8					
67	1	8.9	0.6	3.7	5	18.1	0.299	0.246
	2	12.7	0.8					
	3	10.7	0.6					
	4	17	0.8					
	5W	4.6	0.5					
68	1	13.8	0.7	8.4	4	18.4	0.213	0.291
	2	8.4	0.6					
	3	13.8	0.7					
	4W	5.4	0.5					
69	1	2.9	0.4	10.5	5	14.6	0.274	0.166
	2	10.2	0.6					
	3	15.2	0.6					
	4W	1.1	0.4					
	5W	1	0.3					
70	1	10.1	0.8	4.5	5	20.3	0.38	0.592
	2	5.4	0.6					
	3	15.9	0.9					
	4	17.8	0.8					
	5	11.2	0.5					
71	1	10.6	0.7	8.5	4	18.6	0.231	0.227
	2	16.5	0.7					
	3	14.2	0.6					
	4W	4.9	0.3					
72	1	10.7	0.8	10.3	4	10.6	0.263	0.169
	2	17.2	0.7					
	3	16.7	0.7					
	4W	5.6	0.4					
73	1	10.5	0.6	4.4	5	7.7	0.192	0.074
	2	11	0.6					
	3	14.3	0.7					
	4W	4.9	0.3					
	5W	2.7	0.3					
74	1	21.1	0.9	6.2	6	13.5	0.493	0.307
	2	21	0.9					
	3	14.5	0.6					
	4W	12.8	0.5					
	5W	7.9	0.4					
75	1	10.6	0.8	7.7	6	27.8	0.518	0.545
	2	16.5	1					
	3	20.2	0.9					
	4	14.2	0.6					
	5W	4.8	0.6					
	6W	4.8	0.6					
76	1	10.2	0.9	6.6	5	14	0.449	0.611
	2	16.5	1					
	3	21.5	1					
	4	15.4	0.7					
	5	5.4	0.6					
77	1	8.2	0.6	8.5	4	16	0.189	0.239
	2	14.5	0.7					
	3	3.8	0.5					
	4	14.3	0.6					
78	1	6.4	0.5	2.5	5	17.4	0.189	0.245
	2	11.9	0.7					
	3	13.8	0.7					
	4	8.7	0.4					
	5W	5.2	0.4					
79	1	19.3	0.9	4.8	4	8	0.399	0.175
	2	18.3	0.8					
	3	11.8	0.5					
	4W	15	0.5					
80	1	10.1	0.6	8.8	4	6.3	0.228	0.136
	2	17	0.7					
	3	14.9	0.6					
	4W	5.6	0.4					
81	1	9.1	0.7	1.8	6	17.5	0.334	0.178
	2	15.7	0.8					
	3	14.7	0.7					
	4	8.8	0.4					
	5	4.5	0.4					
	6W	2.7	0.4					
82	1	11.6	0.7	6.2	4	21.8	0.193	0.211
	2	12.1	0.6					
	3	16.6	0.8					
	4	7.3	0.5					
83	1	9.2	0.7	1.4	6	13.7	0.377	0.368
	2	15.9	1					
	3	21.8	1					
	4	16.7	0.7					
	5	10	0.3					
	6W	5.3	0.6					
84	1	13.6	0.9	2.7	5	2.7	0.432	0.127
	2	19.2	1					
	3	16.9	0.8					
	4	10.3	0.4					
	5	8.8	0.6					

Time 0 measurements (May 29, 1996) - Slope/orientation experiment

PLANT #	LEAF #	LEAF LENGTH (cm)	LEAF WIDTH (cm)	SHOOT HEIGHT (cm)	TOTAL # LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
85	1	6.1	0.6	1.3	5	15.6	0.267	0.36
	2	10.8	0.8					
	3	17.2	1					
	4	15.5	0.8					
	5	8.9	0.4					
86	1	8.4	0.8	1.5	5	4	0.375	0.233
	2	14.6	0.8					
	3	15.2	0.7					
	4	8.9	0.4					
	5W	3.9	0.6					
87	1	11.1	0.7	0.8	5	15.6	0.213	0.301
	2	13.6	0.7					
	3	16.6	0.9					
	4	6.7	0.6					
	5	7.8	0.3					
88	1	10.5	0.6	6.6	5	3.6	0.227	0.068
	2	13.1	0.7					
	3	17	0.9					
	4	3.7	0.4					
	5W	1.6	0.5					
89	1	9.8	0.4	1.2	6	4.3	0.41	0.128
	2	8.8	0.6					
	3	14.5	0.9					
	4	17.6	0.7					
	5	21.9	0.9					
	6W	5	0.5					
90	1	11.3	0.7	7.5	5	8.7	0.303	0.102
	2	17.4	0.9					
	3	14.6	0.7					
	4	5.7	0.5					
	5W	3.9	0.4					
91	1	5	0.5	2.7	4	13.9	0.129	0.309
	2	8.3	0.7					
	3	9.6	0.5					
	4	13.1	0.7					
92	1	15	0.8	4.6	5	16.4	0.176	0.259
	2	12	0.6					
	3	8.3	0.7					
	4	5	0.6					
	5W	3	0.5					
93	1	9.6	0.6	2.6	5	7.3	0.292	0.117
	2	15.1	0.8					
	3	16.3	0.8					
	4	9.8	0.4					
	5W	4.6	0.4					
94	1	14.4	0.7	8.4	4	8.1	0.272	0.126
	2	16.1	0.7					
	3	8.4	0.4					
	4W	4.1	0.4					
95	1	11.1	0.7	6.2	5	9.3	0.258	0.157
	2	12.1	0.6					
	3	16.6	0.8					
	4	6.4	0.5					
	5W	3.4	0.4					
96	1	13.5	0.6	13	4	13		
	2	6	0.5					
	3	18	0.7					
	4	13.5	0.6					
97	1	9	0.5	13	4	7.5		
	2	17	0.7					
	3	21	0.9					
	4	14.5	0.5					
98	1	12.5	0.6	11	5	6.5		
	2	17	0.7					
	3	17	0.8					
	4	5	0.5					
	5	11	0.3					

Time 1 measurements - Slope/orientation experiment

Slope	Orientation	Pot #	Plant #	Leaf Length (cm)	Shoot Height (cm)	Total # Leaves	# Dead Leaves	Date
3	N	1	E	12.5	DEAD	1	3	6/17/98
3	N	1	W	12.5	DEAD	1	1	6/17/98
3	N	2	7	15	12	4	1	6/17/98
3	N	2	7	23				6/17/98
3	N	2	7	17				6/17/98
3	N	2	7	22				6/17/98
3	N	2	43	24	14	4	1	6/17/98
3	N	2	43	19				6/17/98
3	N	2	43	19				6/17/98
3	N	2	43	12				6/17/98
3	N	3	21	17	12.5	2	2	6/17/98
3	N	3	21	15				6/17/98
3	N	3	47	15	15.5	3	1	6/17/98
3	N	3	47	21				6/17/98
3	N	3	47	21				6/17/98
3	N	4	25	21	14	3	1	6/17/98
3	N	4	25	18				6/17/98
3	N	4	25	18				6/17/98
3	N	4	12	18	8	3	0	6/17/98
3	N	4	12	19				6/17/98
3	N	4	12	13				6/17/98
3	N	5	18	15	8	4	1	6/17/98
3	N	5	18	19				6/17/98
3	N	5	18	18				6/17/98
3	N	5	18	12				6/17/98
10	N	1	45	15	14	2	1	6/17/98
10	N	1	45	18				6/17/98
10	N	1	49	25	15	3	1	6/17/98
10	N	1	49	21				6/17/98
10	N	1	49	20.5				6/17/98
10	N	2	56	16	17	3	1	6/17/98
10	N	2	56	21				6/17/98
10	N	2	56	25				6/17/98
10	N	2	6	17	7	2	1	6/17/98
10	N	2	6	15				6/17/98
10	N	3	11	18	9	4	1	6/17/98
10	N	3	11	15				6/17/98
10	N	3	11	19				6/17/98
10	N	3	11	6				6/17/98
10	N	3	27	20	7	4	0	6/17/98
10	N	3	27	21				6/17/98
10	N	3	27	15				6/17/98
10	N	3	27	16				6/17/98
10	N	4	35	21	14	4	2	6/17/98
10	N	4	35	18				6/17/98
10	N	4	35	16				6/17/98
10	N	4	35	22				6/17/98
10	N	4	17	21	10	4	2	6/17/98
10	N	4	17	17				6/17/98
10	N	4	17	18				6/17/98
10	N	4	17	12				6/17/98
10	N	5	31B	20	16	3	1	6/17/98
10	N	5	31B	24				6/17/98
10	N	5	31B	26				6/17/98
10	N	5	9	16	14	4	1	6/17/98
10	N	5	9	25				6/17/98
10	N	5	9	19				6/17/98
10	N	5	9	25				6/17/98
25	N	1	63	15	14	2	1	6/17/98
25	N	1	63	18				6/17/98
25	N	2	E	22	13	3	1	6/17/98
25	N	2	E	20				6/17/98
25	N	2	E	27				6/17/98
25	N	2	61	20	DEAD (10)	2	1	6/17/98
25	N	2	61	15				6/17/98
25	N	3	23	18	8	4	2	6/17/98
25	N	3	23	21				6/17/98
25	N	3	23	25				6/17/98
25	N	3	23	12				6/17/98
25	N	3	55A	10	DEAD	1	2	6/17/98
25	N	4	4	14	9	2	2	6/17/98
25	N	4	4	8				6/17/98
25	N	4	26	20	13	4	2	6/17/98
25	N	4	26	17				6/17/98
25	N	4	26	18				6/17/98
25	N	4	26	12				6/17/98
25	N	5	16	19	11	3	2	6/17/98
25	N	5	16	18				6/17/98
25	N	5	16	9.5				6/17/98
25	N	5	37	20	9	3	1	6/17/98
25	N	5	37	22				6/17/98

Time 1 measurements - Slope/orientation experiment

Slope	Orientation	Pot #	Plant #	Leaf Length (cm)	Shoot Height (cm)	Total # Leaves	# Dead Leaves	Date
25	N	5	37	15				6/17/98
3	S	1	41	13	DEAD (8)	1	1	6/17/98
3	S	1	68	16	13	2	2	6/17/98
3	S	1	68	19				6/17/98
3	S	2	51	15.5	11	2	1	6/17/98
3	S	2	51	16				6/17/98
3	S	2	8	17	14	3	1	6/17/98
3	S	2	8	21				6/17/98
3	S	2	8	23				6/17/98
3	S	3	54	16	DEAD	1	1	6/17/98
3	S	3	57	24	14	3	0	6/17/98
3	S	3	57	18.5				6/17/98
3	S	3	57	20.5				6/17/98
3	S	4	60	20	15	3	1	6/17/98
3	S	4	60	25.5				6/17/98
3	S	4	60	14				6/17/98
3	S	4	30	23	11	4	0	6/17/98
3	S	4	30	16				6/17/98
3	S	4	30	19				6/17/98
3	S	4	30	24				6/17/98
3	S	5	50	19	13	1	2	6/17/98
3	S	5	44	19.5	7	3	1	6/17/98
3	S	5	44	15				6/17/98
3	S	5	44	17				6/17/98
10	S	1	31A	DEAD				6/17/98
10	S	1	39	16.5	7	2	2	6/17/98
10	S	1	39	14				6/17/98
10	S	2	55B	19	16	3	1	6/17/98
10	S	2	55B	14				6/17/98
10	S	2	55B	19				6/17/98
10	S	2	40	24	17	4	2	6/17/98
10	S	2	40	19				6/17/98
10	S	2	40	26.5				6/17/98
10	S	2	40	21				6/17/98
10	S	3	62	20.5	12	3	1	6/17/98
10	S	3	62	25				6/17/98
10	S	3	62	18.5				6/17/98
10	S	4	32	19	10	3	2	6/17/98
10	S	4	32	16				6/17/98
10	S	4	32	16				6/17/98
10	S	4	48	11.5	12	3	1	6/17/98
10	S	4	48	20.5				6/17/98
10	S	4	48	24.5				6/17/98
10	S	5	E	17.5	DEAD	1	1	6/17/98
10	S	5	W	15	DEAD	2	1	6/17/98
10	S	5	W	20.5				6/17/98
25	S	1	53	19.5	11	4	2	6/17/98
25	S	1	53	23				6/17/98
25	S	1	53	18				6/17/98
25	S	1	53	24				6/17/98
25	S	1	2	17.5	11.5	2	2	6/17/98
25	S	1	2	18				6/17/98
25	S	2	59	16	7.5	3	1	6/17/98
25	S	2	59	19				6/17/98
25	S	2	59	14.5				6/17/98
25	S	2	46	21	14.5	2	2	6/17/98
25	S	2	46	21.5				6/17/98
25	S	3	65	14	9	4	2	6/17/98
25	S	3	65	21.5				6/17/98
25	S	3	65	15.5				6/17/98
25	S	3	65	20				6/17/98
25	S	3	36	17	11.5	3	1	6/17/98
25	S	3	36	17				6/17/98
25	S	3	36	21				6/17/98
25	S	4	33	20	15	1	3	6/17/98
25	S	4	64	18	DEAD	1	2	6/17/98
25	S	5	3	20	11	3	2	6/17/98
25	S	5	3	17				6/17/98
25	S	5	3	23				6/17/98
25	S	5	15	20	10	4	1	6/17/98
25	S	5	15	15				6/17/98
25	S	5	15	20.5				6/17/98
25	S	5	15	15.5				6/17/98

Time 2 measurements - Slope/orientation experiment

Slope	Orientation	Pot #	Plant #	Leaf Length (cm)	Shoot Height (cm)	Total # Leaves	# Dead Leaves	Date
3	N	1	DEAD	DEAD	DEAD	DEAD	DEAD	7/8/98
3	N	2	7	23	17.5	5	2	7/8/98
3	N	2	7	25				7/8/98
3	N	2	7	21				7/8/98
3	N	2	7	24				7/8/98
3	N	2	7	22.5				7/8/98
3	N	3	47	21	16	2	1	7/8/98
3	N	3	47	21				7/8/98
3	N	4	25	22	21	4	1	7/8/98
3	N	4	25	22.5				7/8/98
3	N	4	25	22.5				7/8/98
3	N	4	25	21				7/8/98
3	N	5	18	18.5	15	4	2	7/8/98
3	N	5	18	19				7/8/98
3	N	5	18	17				7/8/98
3	N	5	18	17.5				7/8/98
10	N	1	49	17	18	3	1	7/8/98
10	N	1	49	25				7/8/98
10	N	1	49	25				7/8/98
10	N	2	56	14	22	4	3	7/8/98
10	N	2	56	19				7/8/98
10	N	2	56	18				7/8/98
10	N	2	56	14				7/8/98
10	N	3	11	13	19	3	4	7/8/98
10	N	3	11	22				7/8/98
10	N	3	11	21				7/8/98
10	N	4	35	21	18	5	2	7/8/98
10	N	4	35	25				7/8/98
10	N	4	35	21				7/8/98
10	N	4	35	23				7/8/98
10	N	4	35	22				7/8/98
10	N	5	9	26	23.5	4	2	7/8/98
10	N	5	9	25				7/8/98
10	N	5	9	22				7/8/98
10	N	5	9	25.5				7/8/98
25	N	1	97	24	13	4	2	7/8/98
25	N	1	97	21				7/8/98
25	N	1	97	23				7/8/98
25	N	1	97	14				7/8/98
25	N	2	61	26	15.5	4	3	7/8/98
25	N	2	61	29				7/8/98
25	N	2	61	22				7/8/98
25	N	2	61	28				7/8/98
25	N	3	23	23	20	5	2	7/8/98
25	N	3	23	27				7/8/98
25	N	3	23	22				7/8/98
25	N	3	23	23				7/8/98
25	N	3	23	23				7/8/98
25	N	4	26	21	13	4	2	7/8/98
25	N	4	26	14				7/8/98
25	N	4	26	19.5				7/8/98
25	N	4	26	20.5				7/8/98
25	N	5	37	22.5	12	4	3	7/8/98
25	N	5	37	23				7/8/98
25	N	5	37	23				7/8/98
25	N	5	37	15.5				7/8/98
3	S	1	68	17	14	3	3	7/8/98
3	S	1	68	20				7/8/98

Time 2 measurements - Slope/orientation experiment

Slope	Orientation	Pot #	Plant #	Leaf Length (cm)	Shoot Height (cm)	Total # Leaves	# Dead Leaves	Date
3	S	1	68	17				7/8/98
3	S	2	8	20.5	10	4	2	7/8/98
3	S	2	8	20.5				7/8/98
3	S	2	8	17				7/8/98
3	S	2	8	14				7/8/98
3	S	3	57	24	13	4	2	7/8/98
3	S	3	57	25				7/8/98
3	S	3	57	23				7/8/98
3	S	3	57	23				7/8/98
3	S	4	30	25	25	5	2	7/8/98
3	S	4	30	27				7/8/98
3	S	4	30	23				7/8/98
3	S	4	30	24				7/8/98
3	S	4	30	19				7/8/98
3	S	5	44	19	9	4	1	7/8/98
3	S	5	44	18				7/8/98
3	S	5	44	20				7/8/98
3	S	5	44	15				7/8/98
10	S	1	39	13	15	4	1	7/8/98
10	S	1	39	20				7/8/98
10	S	1	39	21				7/8/98
10	S	1	39	15				7/8/98
10	S	2	40	25	29	4	2	7/8/98
10	S	2	40	27				7/8/98
10	S	2	40	27				7/8/98
10	S	2	40	26				7/8/98
10	S	3	62	19	15	5	3	7/8/98
10	S	3	62	23				7/8/98
10	S	3	62	20				7/8/98
10	S	3	62	19				7/8/98
10	S	3	62	25				7/8/98
10	S	4	32	19	14	4	2	7/8/98
10	S	4	32	19				7/8/98
10	S	4	32	16				7/8/98
10	S	4	32	18				7/8/98
10	S	5	5	DEAD	DEAD	DEAD	DEAD	7/8/98
25	S	1	53	24	24	5	2	7/8/98
25	S	1	53	24				7/8/98
25	S	1	53	25				7/8/98
25	S	1	53	23				7/8/98
25	S	1	53	24				7/8/98
25	S	2	46	20	20	3	5	7/8/98
25	S	2	46	19				7/8/98
25	S	2	46	16				7/8/98
25	S	3	36	22	12	4	3	7/8/98
25	S	3	36	20				7/8/98
25	S	3	36	18				7/8/98
25	S	3	36	17				7/8/98
25	S	4	64	18	N/A	1	1	7/8/98
25	S	5	15	19	13	4	4	7/8/98
25	S	5	15	19.5				7/8/98
25	S	5	15	20				7/8/98
25	S	5	15	15.5				7/8/98

Time 3 measurements - Slope/orientation experiment

Date	Flag #	Slope	Orientation	Leaf Length	Shoot Height	Total # Leaves	Total Dead Leaves
7/29/98	25-1S	25	S	24	30	8	4
7/29/98				33			
7/29/98				33			
7/29/98				28			
7/29/98	3-3S	3	S	27	15	7	3
7/29/98				31			
7/29/98				19			
7/29/98				32			
7/29/98	10-4S	10	S	14	8	6	3
7/29/98				24			
7/29/98				22			
7/29/98	10-2N	10	N	DEAD	DEAD	DEAD	DEAD
7/29/98	25-1N	25	N	21	17	7	4
7/29/98				17			
7/29/98				19			
7/29/98	3-1N	DEAD	DEAD	DEAD	DEAD	DEAD	DEAD
7/29/98	10-1N	10	N	12	3	5	3
7/29/98				9			
7/29/98	3-3N	3	N	14	9	8	4
7/29/98				14			
7/29/98				12			
7/29/98				9			
7/29/98	3-1S	3	S	29	12	6	3
7/29/98				30			
7/29/98				20			
7/29/98				30			
7/29/98	10-1S	10	S	30	21	6	3
7/29/98				32			
7/29/98				21			
7/29/98	10-2S	10	S	30	22	7	3
7/29/98				28			
7/29/98				27			
7/29/98				32			
7/29/98	NEW			5			
7/29/98	SHOOT			3			
7/29/98	25-3N	25	N	27	35	8	4
7/29/98				35			
7/29/98				35			
7/29/98				23			
7/29/98	3-5N	3	N	22	18	8	4
7/29/98				27			
7/29/98				27			
7/29/98				12			
7/29/98	3-4N	3	N	26	26	8	4
7/29/98				29			
7/29/98				30			
7/29/98				16			
7/29/98	10-3N	10	N	27	17	8	4
7/29/98				22			
7/29/98				30			
7/29/98				20			
7/29/98	25-5N	25	N	28	23	7	3
7/29/98				27			
7/29/98				24			
7/29/98				13			

Time 3 measurements - Slope/orientation experiment

Date	Flag #	Slope	Orientation	Leaf Length	Shoot Height	Total # Leaves	Total Dead Leaves
7/29/98	25-4N	25	N	15	6	8	4
7/29/98				10			
7/29/98				11			
7/29/98				14			
7/29/98	10-4N	10	N	26	26	9	5
7/29/98				31			
7/29/98				18			
7/29/98				31			
7/29/98	3-2N	3	N	25	25	8	3
7/29/98				30			
7/29/98				29			
7/29/98				16			
7/29/98				25			
7/29/98	25-2N	25	N	33	30	6	2
7/29/98				32			
7/29/98				42			
7/29/98				18			
7/29/98	10-5N	10	N	31	22	8	4
7/29/98				24			
7/29/98				30			
7/29/98				26			
7/29/98	25-4S	25	S	ALREADY DEAD		DEAD	DEAD
7/29/98	10-5S	10	S	ALREADY DEAD		DEAD	DEAD
7/29/98	25-5S	25	S	23	26	8	4
7/29/98				28			
7/29/98				28			
7/29/98				15			
7/29/98	3-5S	5	S	18	9	7	3
7/29/98				24			
7/29/98				22			
7/29/98				15			
7/29/98	3-2S	3	S	19	14	7	3
7/29/98				27			
7/29/98				18			
7/29/98				22			
7/29/98	25-3S	25	S	30	19	8	5
7/29/98				26			
7/29/98				24			
7/29/98	25-2S	25	S	37	30	5	3
7/29/98				30			
7/29/98	3-4S	3	S	34	22	7	3
7/29/98				35			
7/29/98				28			
7/29/98				30			
7/29/98	10-3S	10	S	34	24	7	4
7/29/98				27			
7/29/98				32			

Time 4 measurements - Slope/orientation experiment

FLAG #	PLANT #	LEAF LENGTH	SHOOT HT	#LIVE LEAVES	# DEAD LEAVES	NOTES
25-1N	97	25	21.5	3	2	
		26.6				
		21				
10-2N	DEAD					DEAD
3-3N	47	19.5	13	3	1	CRAB SLICED
		19.5				
		17				
10-1N	49	19	7	3	0	
		16				
		24				
3-1N	DEAD					DEAD
3-5S	44	23.5	14.5	4	2	
		26				
		25				
		24.5				
3-2S	8	22.5	23.5	4	2	
		31				
		32				
		24				
3-1S	68	28	20.5	4	2	
		28.5				
		26.5				
		31				
10-1S	39	31	23.5	3	1	
		25.5				
		30				
10-2S	40	30	24	4	3	
		27.5				
		22				
		31				
25-3N	23	27	31	5	3	
		35				
		35.5				
		25				
		34				
3-5N	18	33	18	3	5	
		26				
		31				
3-4N	25	31	24	4	5	
		28.5				
		25				
		26				
10-3N	11	28	25	3	3	
		28				
		30				
25-5N	37	30	20	4	4	
		25				
		30				
		27				
25-4N	26	28	13	4	5	
		19				
		21				
		12				
10-4N	35	25	15	5	4	
		30				

Time 4 measurements - Slope/orientation experiment

FLAG #	PLANT #	LEAF LENGTH	SHOOT HT	#LIVE LEAVES	# DEAD LEAVES	NOTES
		30				
		28				
		21				
3-2N	7	23	14	5	3	
		29				
		20				
		25				
		29				
25-2N	61	31	40	4	3	
		40				
		35				
		39				
10-5N	9	31	31	3	4	
		26				
		30				
25-4S	64					NO PLANTS
10-5S	DEAD					DEAD
25-5S	15	30	20	4	3	
		30				
		21				
		28				
25-3S	36	30	23	3	2	
		28				
		29				
	36NS	9.7	9	1	2	
25-2S	46	37	19	3	3	
		27				
		35				
10-3S	62	35	20	5	3	
		26				
		34				
		29				
		21				
3-4S	30	30	12	5	2	
		35				
		21				
		29				
		32				
25-1S	53	35	25	4	5	VERY DRY
		31				
		26				
		32				
3-3S	57	DEAD				DEAD
	57NS					
10-4S	32	25	13	3	4	
		22				
		24.5				

TIME final MEASUREMENTS - Slope/orientation experiment

SLOPE	ORIENT.	POT #	PLANT #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	# LIVE LEAVES	# DEAD LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)
10	N	2	58	DEAD						0	0
3	S	1	68	30	0.6	12	4	3	15.0	0.815	1.231
				28	0.7						
				28	0.8						
				18	0.2						
10	S	1	39	30	0.7	15	3	3	17.0	0.773	1.663
				19	0.4						
				25	0.7						
			39NS	5	0.3		2	0			
				6	0.3						
10	S	2	40	32	0.8	19	5	5	15.0	1.616	2.880
				30	0.7						
				30	0.8						
				22	0.5						
				13	0.3						
			40NS	6	0.3		4	0			
				5	0.3						
				6	0.3						
				4	0.3						
			40NS2	5	0.3		2	0			
				3.5	0.3						
3	N	5	18	32	0.8	16	5	3		1.282	1.070
				31	0.8						
				18	0.4						
				32	0.8						
				27	0.8						
10	N	1	48NS	24	0.8	8	4	0		0.938	1.130
				21	0.7						
				11	0.4						
				18	0.6						
10	S	4	32	25	0.7	21	4	3	6.0	0.785	0.698
				25	0.7						
				11	0.3						
				18	0.7						
25	N	2	61	40	0.8	33	4	2	15.0	1.315	1.618
				37	0.8						
				27	0.8						
				38	0.9						
25	N	3	23	35	0.7	38	6	4	16.0	1.871	3.382
				35	0.8						
				28	0.8						
				15	0.4						
				38	0.8						
			23NS	3	0.3		2	0			
				4	0.3						
			23NS2	2	0.3		2	0			
				2.5	0.3						
			23NS3	2	0.3		1	0			
25	S	5	15	28	0.9	29	4	3	11.0	1.105	0.776
				32	0.8						
				24	0.7						
				30	0.8						
			15NS	1.5	0.3		2	0			
				1.5	0.3						
3	S	5	44	23	0.7	23	5	2	9.0	0.900	0.778
				28	0.7						
				27	0.7						
				25	0.7						
				12	0.3						
			44NS	3	0.3		2	0			
				1	0.3						
			44NS2	3	0.3		2	0			
				1	0.3						
3	N	3	47	20	0.8	0	3	1	15.0	0.728	1.114
				12	0.6						
				17	0.6						
10	N	5	9	29	0.6	26	6	3	27.0	1.317	1.467
				30	0.7						
				15	0.4						
				28	0.7						
				33	0.8						
3	S	3	57NS	8	0.3		3	0	34.0	1.024	1.359
				7	0.4						
				6	0.3						
25	N	1	97	21	0.8	13	4	3	3.0	1.006	0.828
				27	0.7						
				25	0.7						
				18	0.4						
			97NS	5	0.3		2	0			
				5	0.3						
10	S	3	62	21	0.5	21	4	3	7.5	1.680	2.391
				8	0.2						
				35	0.8						
				27	0.7						
				38	0.9						
			62NS	7	0.3	5.5	3	0			
				7	0.3						
				4	0.3						
25	S	3	36	30	0.7	10.5	4	2	4.0	0.904	0.774
				18	0.3						
				27	0.6						
				30	0.8						
			36NS	2.5	0.3		2	0			
				2	0.3						
25	S	2	46	34.5	0.8	18.5	3	2	7.0	1.012	0.901
				11	0.2						
				29	0.6						
				38	0.9						
25	S	1	53	33	0.8	13.5	4	5	14.0	2.349	3.053
				32	0.8						

TIME final MEASUREMENTS - Slope/orientation experiment

SLOPE	ORIENT.	POT #	PLANT #	LEAF LENGTH (cm)	LEAF WIDTH(cm)	SHOOT HEIGHT (cm)	# LIVE LEAVES	# DEAD LEAVES	LENGTH OF RHIZOME (cm)	AG DRY WT (g)	BG DRY WT (g)	
				17	0.3							
				27	0.7							
			53NS	4	0.3		3	0				
				3	0.3							
				3	0.3							
10	N	3	11	30	0.8	14	4	3	2.0	1.153	0.752	
				20	0.6							
				27	0.7							
				28	0.7							
			11NS	1.5	0.3		3	0				
				4.5	0.3							
				3	0.3							
25	N	5	37	28	0.7	25	4	3	8.0	1.515	1.487	
				31	0.8							
				28	0.8							
				31	0.7							
				14	0.3							
10	N	4	35	8	0.3	17	4	3	8.0	1.812	2.328	
				32	0.7							
				28	0.8							
				20	0.6							
				21	0.7							
			35NS	8	0.3		5	0				
				4	0.3							
				7	0.3							
				2	0.3							
				2	0.3							
25	N	4	26	11	0.2	19	4	8	6.0	0.935	0.967	
				11.5	0.6							
				28.5	0.8							
				28.5	0.7							
				22	0.7							
3	N	2	7	30	0.6	14	4	4	13.0	1.428	2.677	
				27	0.8							
				23	0.6							
				8	0.2							
				30	0.7							
			7NS	3	0.3		3	0				
				5.5	0.3							
				8	0.3							
10	S	5	56	DEAD								DEAD
3	S	2	8	23	0.8	15	5	2	11.0	1.400	1.288	
				32	0.8							
				22	0.5							
				34	0.8							
				8	0.2							
				24	0.7							
			8NS	5	0.3		4	0				
				8	0.3							
				4	0.3							
				5.5	0.3							
3	S	4	30	11	0.3	18.5	5	3	10.0	2.048	1.841	
				30	0.8							
				38	0.8							
				25	0.6							
				30	0.8							
				33	0.7							
			30NS	7.5	0.3		3	0				
				7.5	0.3							
				7.5	0.3							
25	S	4	64	DEAD						0.000	0.000	DEAD
3	N	1	14	DEAD						0.000	0.000	DEAD
10	N	2	6	DEAD								DEAD
3	N	4	25	29.5	0.8		4	3	15.0	1.282	2.458	
				31	0.7							
				29	0.8							
				27	0.7							

Slope/orientation experiment - Soil temperatures in pots and next to pots on Aug. 25, 1998

SLOPE	N/S	TEMP IN POT (°C)	TEMP NXT TO POT (°C)
3	N	24	25
3	N	25	26
3	N	25	24
3	N	25	23
3	N	25	24
10	N	24	22
10	N	26	26
10	N	24	23
10	N	23	23
25	N	24	23
25	N	23	22
25	N	24	24
25	N	22	23
25	N	23	24
3	S	25	24
3	S	25	25
3	S	24	25
3	S	23	23
3	S	24	25
10	S	24	25
10	S	24	24
10	S	23	23
10	S	25	24
10	S	26	26
25	S	26	22
25	S	23	23
25	S	25	23
25	S	23	24
25	S	24	23

Results of physical characteristics measured at 32 salt marsh sites (six constructed and 26 natural) in the Great Bay Estuary, Summer 1996. All values are mean per site except for lengths and site orientations.

Marsh Type	Site Number	Length (m)	Width (m)	Site Orientation (°)	Fetch (m)	Slope (m)	North-south Orientation (°)*
Constructed	1	17	7	42	70	14.9	42
Constructed	3	100	20	171	583	1.0	171
Constructed	4	154	3	225	103	5.9	135
Constructed	5	38	2	160	13	21.9	160
Constructed	7	182	19	351	310	4.8	9
Constructed	31	47	3.6	192	3	3.6	168
Natural	2	193	11	63	107	12.0	63
Natural	6	148	18	159	517	6.5	159
Natural	8	168	13	180	303	7.8	180
Natural	9	179	32	238	387	3.8	122
Natural	10	72	9	145	197	6.9	145
Natural	11	118	11.4	130	203	7.0	130
Natural	12	128	7	245	140	14.4	115
Natural	13	81	17	95	277	8.5	95
Natural	14	77	7.8	170	470	11.0	170
Natural	15	54	12.6	156	493	8.5	156
Natural	16	51	16.6	348	623	3.9	12
Natural	17	64	16.4	166	323	12.5	166
Natural	18	67	9.3	228	197	7.5	132
Natural	19	26	6	58	123	12.1	58
Natural	20	124	4.6	36	250	25.1	36
Natural	21	65	18.4	68	817	6.7	68
Natural	22	72	3.4	48	53	19.4	48
Natural	23	144	6.8	0	45	11.6	0
Natural	24	99	12.9	78	710	9.4	78
Natural	25	32	7.2	90	803	13.1	90
Natural	26	172	10.3	142	425	7.3	142
Natural	27	62	11	166	527	9.6	166
Natural	28	272	8.6	214	193	7.9	146
Natural	29	79	6.1	64	45	23.7	64
Natural	30	71	7.6	48	170	7.2	48
Natural	32	41	6.3	274	6	6.4	86

* If compass reading was greater than 180, it was subtracted from 360 to give the N/S orientation value

Functional indicator values for each of 6 constructed and 11 reference salt marsh sites in the Great Bay Estuary, summer 1996.
All values are means ±1 SE except for marsh age, number of plant species per site and H values.

SITE	MARSH TYPE	AGE (yrs)	Aboveground Biomass (g/m^2)	Sediment deposited* ($g\ sed/m^2/day$)	Soil organic matter content (%)	No. plant species (all Quadrats)	No. plant species (9 quadrats)	Shannon-Weiner Index (H)	Percent cover *Spartina alterniflora*	Percent cover SP,DS,JG**
1	Constructed	2	14.3 ±3.4	7.5632	1.26 ±0.1	1	1	0.0000	11	0
3	Constructed	6	199.6 ±87.1	5.3158	2.26 ±0.7	5	2	0.0336	38	<1
4	Constructed	1	3.1 ±0.9	8.2865	1.84 ±0.3	2	2	0.1636	1	0
5	Constructed	2	32.7 ±10.2	8.8445	1.28 ±0.1	5	5	0.3439	8	0
7	Constructed	3	395.6 ±164.2	10.4652	3.21 ±1.5	4	2	0.0087	42	0
31	Constructed	14	309.8 ±40.7	0.945	15.27 ±1.2	9	9	0.5114	29	37
2	Reference	-	470.6 ±80.3	2.0763	31.04 ±2.6	13	4	0.2273	20	47
6	Reference	-	345.2 ±108.1	0.3656	7.15 ±2.3	10	5	0.2974	22	22
8	Reference	-	474.3 ±130	9.3459	16.57 ±2.8	9	6	0.3339	35	21
12	Reference	-	245.5 ±36.1	3.9788	29.25 ±1.2	9	7	0.3903	34	11
19	Reference	-	352.3 ±91.7	2.1403	29.05 ±4.6	9	7	0.3771	26	12
22	Reference	-	272.1 ±48.7	1.5489	32.37 ±2.8	4	3	0.2282	35	5
24	Reference	-	123.7 ±27.2	1.4266	7.85 ±2.7	7	3	0.2601	25	9
26	Reference	-	430.5 ±128.6	1.4557	30.88 ±0.5	12	5	0.4901	19	38
29	Reference	-	216.9 ±44.4	1.6048	20.43 ±9.7	9	9	0.6211	26	13
30	Reference	-	364.6 ±73.0	3.721	20.13 ±5.3	2	2	0.0604	55	1
32	Reference	-	536.8 ±140.9	0.9723	28.30 ±6	8	7	0.2577	5	84

*Numbers are means of trial 1 and trial 2.
** *Spartina patens*, *Distichlis spicata* and *Juncus gerardii*

Aboveground biomass raw data from 6 constructed and 11 reference salt marsh sites in the Great Bay Estuary, summer 1996.

SITE	QUADRAT	Aboveground biomass (g/m^2)
1	1	3.3
1	2	21.4
1	3	11.7
1	4	13.1
1	5	9.9
1	6	26.3
2	1	214
2	2	546
2	3	722.8
2	4	598.4
2	5	476.8
2	6	265.76
3	1	536.6
3	2	274.48
3	3	41.32
3	4	317.84
3	5	0
3	6	27.56
4	1	2.0
4	2	1.3
4	3	1.9
4	4	3.2
4	5	2.6
4	6	7.4
5	1	25.8
5	2	10.5
5	3	11.9
5	4	19.6
5	5	66.0
5	6	62.3
6	1	223.72
6	2	343.64
6	3	340.84
6	4	204.12
6	5	853.76
6	6	105.28
7	1	1108.76
7	2	72.28
7	3	472.12
7	4	506.84
7	5	32.92
7	6	180.92
8	1	186.2
8	2	361.44
8	3	670.44
8	4	515.44
8	5	133.44
8	6	978.8

SITE	QUADRAT	Aboveground biomass (g/m^2)
12	1	316.56
12	2	321.92
12	3	131.04
12	4	136.84
12	5	270.12
12	6	296.4
19	1	355.28
19	2	167.2
19	3	633.24
19	4	617.28
19	5	135.36
19	6	205.24
22	1	436.04
22	2	249.6
22	3	305.76
22	4	300.36
22	5	67.24
22	6	273.4
24	1	201.32
24	2	51.96
24	3	119.92
24	4	180.04
24	5	39.12
24	6	150.04
26	1	204.6
26	2	1033
26	3	196.6
26	4	418.6
26	5	461.8
26	6	268.64
29	1	141.4
29	2	303.68
29	3	395.12
29	4	174.76
29	5	116.08
29	6	170.56
30	1	169.28
30	2	311.72
30	3	397.56
30	4	179.32
30	5	606
30	6	523.68
31	1	211.52
31	2	430.12
31	3	177.68
31	4	365.52
31	5	295.4
31	6	378.48
32	1	73.84
32	2	660
32	3	757.04
32	4	359.8
32	5	833.4
32	6	

Amount of sediment deposited on individual traps at constructed and reference sites. Traps were left on the marsh surface for three weeks, beginning on July 18 (Trial 1) and August 7 (Trial 2), 1996.

Trial	Site	Marsh Type	Trap#	Sed/area/time ($g/m^2/day$)	MEAN ($g/m^2/day$)/site	SD	SE
1	1	C	1	9.0926	5.9318	2.7274	1.2197
1	1	C	2	8.7206			
1	1	C	3	3.7699			
1	1	C	4	3.7739			
1	1	C	5	4.3021			
1	3	C	1	0.5267	3.3060	2.5963	1.1611
1	3	C	2	2.3318			
1	3	C	3	4.4270			
1	3	C	4	2.0177			
1	3	C	5	7.2268			
1	4	C	1	3.0349	4.3516	3.2600	1.4579
1	4	C	2	2.9961			
1	4	C	3	2.7235			
1	4	C	4	2.8250			
1	4	C	5	10.1788			
1	5	C	1	6.1005	11.6936	13.4779	6.0275
1	5	C	2	5.9772			
1	5	C	3	3.3880			
1	5	C	4	7.3360			
1	5	C	5	35.6663			
1	7	C	1	4.4113	15.3744	23.0301	10.2994
1	7	C	2	7.3451			
1	7	C	3	4.1663			
1	7	C	4	56.5057			
1	7	C	5	4.4437			
1	31	C	1	1.2683	0.9038	0.2283	0.1021
1	31	C	2	0.8515			
1	31	C	3	0.7212			
1	31	C	4	0.9639			
1	31	C	5	0.7142			
1	2	N	1	8.2362	2.8124	3.2541	1.4553
1	2	N	2	1.3846			
1	2	N	3	0.3094			
1	2	N	4	0.7391			
1	2	N	5	3.3929			
1	6	N	1	0.1759	0.3214	0.1285	0.0575
1	6	N	2	0.2063			
1	6	N	3	0.3895			
1	6	N	4	0.3529			
1	6	N	5	0.4827			
1	8	N	1	5.2835	7.6132	5.2857	2.3638
1	8	N	2	4.0343			
1	8	N	3	8.7880			
1	8	N	4	3.6186			
1	8	N	5	16.3415			
1	12	N	1	2.3734	1.4346	0.8648	0.3867
1	12	N	2	1.0753			
1	12	N	3	0.6973			
1	12	N	4	0.6694			
1	12	N	5	2.3575			
1	19	N	1	3.2557	2.0903	0.9634	0.4308
1	19	N	2	1.8780			
1	19	N	3	2.2699			
1	19	N	4	0.6197			
1	19	N	5	2.4281			
1	22	N	1	0.4486	1.5440	2.0468	0.9153
1	22	N	2	0.2338			
1	22	N	3	1.7069			
1	22	N	4	5.0422			

Amount of sediment deposited on individual traps at constructed and reference sites. Traps were left on the marsh surface for three weeks, beginning on July 18 (Trial 1) and August 7 (Trial 2), 1996.

Trial	Site	Marsh Type	Trap#	Sed/area/time ($g/m^2/day$)	MEAN ($g/m^2/day$)/site	SD	SE
1	22	N	5	0.2885			
1	24	N	1	0.1654	1.8742	1.9258	0.8612
1	24	N	2	4.8207			
1	24	N	3	0.1571			
1	24	N	4	2.4051			
1	24	N	5	1.8225			
1	26	N	1	2.9831	1.4577	0.9326	0.4171
1	26	N	2	1.1905			
1	26	N	3	0.8596			
1	26	N	4	1.6303			
1	26	N	5	0.6251			
1	29	N	1	0.7480	1.2042	0.8324	0.3723
1	29	N	2	1.6084			
1	29	N	3	0.3113			
1	29	N	4	2.4370			
1	29	N	5	0.9161			
1	30	N	1	4.6851	2.6117	1.4796	0.6617
1	30	N	2	2.0302			
1	30	N	3	1.2245			
1	30	N	4	1.5130			
1	30	N	5	3.6058			
1	32	N	1	0.5073	1.0886	1.0251	0.4584
1	32	N	2	0.4735			
1	32	N	3	2.8737			
1	32	N	4	1.0464			
1	32	N	5	0.5421			
2	1	C	1	9.4108	9.1945	8.4446	3.7765
2	1	C	2	23.6379			
2	1	C	3	2.9082			
2	1	C	4	4.0042			
2	1	C	5	6.0117			
2	3	C	1	0.5363	7.3255	9.8323	4.3972
2	3	C	2	4.7622			
2	3	C	3	4.5632			
2	3	C	4	2.1353			
2	3	C	5	24.6306			
2	4	C	1	3.9861	12.2213	19.3017	8.6320
2	4	C	2	4.1723			
2	4	C	3	2.8756			
2	4	C	4	3.3359			
2	4	C	5	46.7368			
2	5	C	1	5.6020	5.9954	2.1669	0.9691
2	5	C	2	9.4597			
2	5	C	3	4.0521			
2	5	C	4	4.3794			
2	5	C	5	6.4837			
2	31	C	1	1.0065	0.9862	0.3164	0.1415
2	31	C	2	0.6104			
2	31	C	3	0.8627			
2	31	C	4	1.4794			
2	31	C	5	0.9721			
2	2	N	1	0.5625	1.3401	1.2783	0.5717
2	2	N	2	2.7309			
2	2	N	3	0.1402			
2	2	N	4	2.7255			
2	2	N	5	0.5417			
2	6	N	1	0.0945	0.4097	0.3100	0.1387
2	6	N	2	0.1782			
2	6	N	3	0.8637			

Amount of sediment deposited on individual traps at constructed and reference sites. Traps were left on the marsh surface for three weeks, beginning on July 18 (Trial 1) and August 7 (Trial 2), 1996.

Trial	Site	Marsh Type	Trap#	Sed/area/time (g/m^2/day)	MEAN (g/m^2/day)/site	SD	SE
2	6	N	4	0.3531			
2	6	N	5	0.5587			
2	7	N	1	4.2872	5.5561	2.5995	1.2997
2	7	N	2	2.5075			
2	7	N	3				
2	7	N	4	7.5606			
2	7	N	5	7.8690			
2	8	N	1		11.0786	13.2041	6.6020
2	8	N	2	4.2093			
2	8	N	3	6.0901			
2	8	N	4	3.2112			
2	8	N	5	30.8036			
2	12	N	1	24.1027	6.5231	9.9978	4.4711
2	12	N	2	0.5227			
2	12	N	3	2.6712			
2	12	N	4	0.4142			
2	12	N	5	4.9048			
2	19	N	1	2.9055	2.1903	0.5380	0.2406
2	19	N	2	2.4226			
2	19	N	3	2.3014			
2	19	N	4	1.5608			
2	19	N	5	1.7615			
2	22	N	1	0.6529	1.5537	2.2374	1.0006
2	22	N	2	0.3608			
2	22	N	3	0.7451			
2	22	N	4	5.5469			
2	22	N	5	0.4630			
2	24	N	1	0.3490	0.9790	1.0773	0.4818
2	24	N	2	0.0406			
2	24	N	3	0.2445			
2	24	N	4	2.4254			
2	24	N	5	1.8352			
2	26	N	1	3.4276	1.4536	1.1805	0.5279
2	26	N	2	1.2591			
2	26	N	3	1.4697			
2	26	N	4	0.6731			
2	26	N	5	0.4385			
2	29	N	1	0.5154	2.0053	1.7263	0.7720
2	29	N	2	1.0680			
2	29	N	3	4.3424			
2	29	N	4	3.3458			
2	29	N	5	0.7551			
2	30	N	1	3.7219	4.8303	3.3641	1.5045
2	30	N	2	3.3920			
2	30	N	3	2.8973			
2	30	N	4	3.3151			
2	30	N	5	10.8251			
2	32	N	1	0.3264	0.8560	0.6619	0.2960
2	32	N	2	0.2324			
2	32	N	3	1.8266			
2	32	N	4	1.1964			
2	32	N	5	0.6981			

Percent soil organic matter raw data from 6 constructed and 11 reference salt marsh sites in the Great Bay Estuary, summer 1996.

SITE	TYPE	%OM
1	C	1.177
1	C	1.221
1	C	1.383
2	N	26.237
2	N	31.514
2	N	35.360
3	C	3.465
3	C	1.141
3	C	2.181
4	C	2.418
4	C	1.636
4	C	1.452
5	C	1.490
5	C	1.221
5	C	1.134
6	N	5.272
6	N	11.777
6	N	4.393
7	C	6.295
7	C	1.636
7	C	1.698
8	N	11.014
8	N	18.614
8	N	20.088
12	N	26.847
12	N	30.135
12	N	30.723
19	N	21.657
19	N	37.353
19	N	28.129
22	N	37.916
22	N	29.535
22	N	29.665
24	N	7.474
24	N	3.324
24	N	12.744
26	N	30.920
26	N	30.006
26	N	31.721
29	N	28.543
29	N	31.633
29	N	1.125
30	N	9.592
30	N	25.575
30	N	25.234
31	C	13.769
31	C	14.523
31	C	17.525
32	N	16.395
32	N	34.526
32	N	33.972

Mean percent cover of plant species at 6 constructed and 11 reference salt marsh sites in the Great Bay Estuary, summer 1996.

SITE	TYPE	*Agropyron pungens*	*Aster sp.*	*Atriplex patula*	*Carex palaceae*	*Distichlis spicata*	*Glaux maritima*	*Juncus gerardii*	*Limonim nashii*	*Panicum virgatum*	*Plantago maritima*	*Potentilla answerina*	*Salicornia europeae*	*Scirpus maritimus*	*Scirpus pungens*	*Solidago sempervirens*	*Spartina alterniflora*	*Spartina patens*	*Spergularia marina*	*Sueda maritima*	*Triglochin maritimum*	unknown
1	constructed																11					
3	constructed								<1				<1				38	<1		<1		
4	constructed												<1				1					
5	constructed			<1							<1		<1				8			1		
7	constructed			<1									<1				42			<1		
31	constructed			<1				8			<1		<1			<1	29	29			1	<1
2	reference	<1		<1	4			11	<1	<1	<1	<1	<1	<1		<1	20	36				
6	reference			<1			<1	<1	<1		<1		<1			<1	22	22		<1		
8	reference			<1				2	<1		<1		<1			<1	35	19		<1		
12	reference			<1					<1		2		<1			<1	34	11	<1	1		
19	reference			2				<1			<1		<1			<1	26	11	<1	2		
22	reference												<1				35	5		<1		
24	reference			<1					<1		<1		<1				25	9		<1		
26	reference	<1	<1	<1		11		8	<1				<1			3	19	19		<1		<1
29	reference			<1				6	<1		2		<1			<1	26	6		1		
30	reference																55	1				
32	reference	<1		<1				16			1					2	5	68				<1

Decorana results (PC-ORD) for plant species percent cover values at six constructed and eleven reference salt marsh sites in the Great Bay Estuary, summer 1996.

SITE	AXIS 1	AXIS 2
1	7.24	106.12
3	6.06	107.56
4	4.04	109.49
5	0	119.35
7	6.86	106.59
31	105.55	45.57
2	135.14	0
6	88.52	46.66
8	70.67	61.89
12	47.75	81.12
19	57.74	67.62
22	27.18	90.84
24	51.19	73.86
26	140.39	113.61
29	68.07	83.84
30	10.98	103.22
32	168.21	3.38