EFFECTS OF ADDING SEDIMENT TO A FRESH WATER THIN MAT FLOATING MARSH

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Oceanography and Coastal Sciences

by
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B.A., Louisiana State University, 2001
December 2005

ACKNOWLEDGMENTS

I would like to extend a great deal of thanks to Jay Gore for all the hard work he did for me in preparation for and during this project. Also, thanks to Joe Baustian, Gary Peterson, and Kristi Rotundo for helping me in the field. For assistance with statistical analysis and thesis revisions, I would like to thank Dr. Jenneke Visser. Thanks to Elaine Evers for her expert map-making skills. A big thank-you goes to my committee members, Dr. Ronald DeLaune and Dr. Robert Carney. For reviewing my thesis and giving valuable input, I thank Dr. Jim Gosselink. To Dr. Charles Sasser, my major professor, I thank you for your help, patience, and confidence in me. Most of all, I thank my family (Mom, Dad, Claire, and Will), Andy Hoefer, and Melissa Baustian for always giving me moral support and encouragement.

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ABSTRACT

Floating marshes are wetlands of emergent vascular vegetation which have a significant mat of live and dead roots, decomposing and dead organic material, and mineral sediments. This mat moves vertically as ambient water levels rise and fall. These marshes have unique hydrology in that overland sheet flow is reduced or eliminated leaving no inorganic sediment input, but there is extensive belowground water exchange. The effect of significant sediment introduction into wetlands with floating marshes is unknown. The purpose of this study was to observe the marsh mat response to Mississippi River sediment addition and measure species composition change and growth response of vegetation.

Study sites were Cypress Canal in Barataria Basin and Turtle Bayou in Terrebonne Basin, Louisiana, USA. Both are thin-mat floating marshes dominated by *Eleocharis baldwinii*. At each site, twenty plots were constructed around a boardwalk built on the marsh. Each 1 m^2 plot was randomly assigned one of five treatments: low, medium, and high sediment additions, and two controls.

With increasing sediment addition, there were significant increases in bulk density and significant decreases in percent organic matter in the top 25 cm of the marsh mat. No significant differences in water level over the mat were found between treatments, indicating that buoyancy was not affected by sediment addition. Vegetation species composition after one growing season was not affected by the addition of sediment to the marsh mat. The number of species present was not affected. Aboveground biomass showed trends of increase with sediment addition, though these trends were not statistically significant. Belowground biomass was not significantly affected by the addition of sediment. Neither plant tissue nutrients nor soil nutrient levels showed much significant change with the addition of sediment to the marsh. Most of the sediment added remained in the top 25 cm of the marsh mat.

Results presented suggest that some addition of sediment to the surface of a fresh water thin-mat floating marsh will not negatively affect the buoyancy of the mat. Increased bulk density facilitates increased vegetative growth, as is found in prior studies. Future data must be collected to determine more definite results.

INTRODUCTION

Floating marshes are wetlands of emergent vascular vegetation with a mat of live and dead roots, decomposing and dead organic material and mineral sediments. This mat moves vertically as ambient water levels rise and fall. The floating marsh mat is often thick enough to support a person's weight, and because it floats, is rarely inundated (Sasser et al., 1991) (Sasser, 1994). Because they float, the marshes are always wet but rarely flooded, reducing stress (Sasser and Gosselink, 1984). The hydrology in these areas is unique in that overland sheet flow of water is reduced or eliminated leaving no inorganic sediment input at the mat surface. Also, below-mat water exchange between the marsh and adjacent open water may be more extensive and direct than an attached marsh (Swarzenski et al., 1991) (Sasser and Gosselink, 1984). The constant hydroperiod gives the floating marsh a degree of environmental stability that is not found in other vegetation types (Sasser et al., 1995b).

The extensive floating marshes in coastal Louisiana probably formed in the later stages of the delta cycle (Sasser, 1994). In early abandonment, when a delta is near its maximum development, the river bypasses the fresh marshes in the portion of the delta lobe farthest from the ocean. The hydraulic energy in these marshes decreases and little sediment is carried into them, resulting in the accumulation of peat. Eventually, the river abandons the delta completely for a more efficient route. This land begins to submerge because of the loss of sediment input from the river. When a delta is abandoned, vegetation thrives in the abandoned upper delta lobe. Deep layers of organic peat accumulate and replace mineral sediment as the primary depositional material. At this stage of the delta cycle, floating marshes begin to form. As the natural attached organic marshes submerge in the destruction phase, the buoyant organic mat is subjected to increasing upward tension until it breaks free from its mineral substrate and floats (Sasser, 1994).

Floating marshes occur throughout the world, including Africa, Australia, Brazil, Canada, Holland, Romania, Tasmania, Switzerland, and the United States. They are present in quiet, protected, low-energy environments (Sasser et al., 1995a). Five types, locally called flotant, occur in Louisiana (Sasser et al., 1996). One type, the *Panicum* thick mat marsh, has three variants. The first variant is dominated by *Panicum hemitomon*. The mat floats on a layer of "free" (clear) water. A second variant is similar to the first, but floats on a layer of ooze, a fluid layer of decomposing organic material (Sasser et al., 1996). A third variant of the *Panicum* thick mat marsh is a site with an abundance of *Myrica cerifera* (wax myrtle). This mat floats on "free" water.

A fourth type of floating marsh in Louisiana is the *Sagittaria* thick mat marsh. These mats are dominated by *Sagittaria lancifolia*. The fifth type of flotant found in Louisiana is the *Eleocharis* thin mat marsh, dominated by *Eleocharis baldwinii*, *Eleocharis parvula*, *Ludwigia leptocarpa*, *Phyla nodiflora*, and *Bidens laevis*. Thin mat marshes are < 25 cm thick, are sometimes seasonally floating, and are supported by substrates that contain very low mineral densities (<0.015 g/cc in the active root zone) and high (>78%) organic matter content.

Floating marshes are widely distributed in the freshwater and oligohaline zones of Louisiana in the Mississippi River Deltaic Plain (Evers et al., 1996). Floating marshes were first mapped and described in Louisiana by Russell (1942) and O'Neil (1949). The freshwater floating marshes were described as being dominated by *Panicum hemitomon* and were extensive, covering 100,000 ha of coastal Louisiana (O'Neil, 1949). Presently, they occupy at least 144,000 ha within Barataria and Terrebonne Basins (Sasser et al., 1996) (Evers et al., 1996), and make up about 70% of the total vegetated area of the freshwater and oligohaline zones. The question of long-term stability in these marshes is important in southern Louisiana, where there is extensive coastal wetland loss. Louisiana has 41% of the nation’s coastal wetlands and also has the highest rate of loss, which has exceeded 1,700 ha/yr (Baumann and Turner, 1990). In parts of the coastal plain, Sasser et al. (1995b) explain, floating freshwater marshes appear to be relatively stable in some areas despite widespread degradation of the attached brackish and salt marshes in the same basins. However, Visser et al (1999) show how *Panicum hemitomon* dominated flotant in other areas has converted in the last forty years to thin-mat flotant.

In 1993, the Louisiana Coastal Wetlands Restoration Plan was developed to address the objectives of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) (Public Law 101-646). One of the restoration priorities of this plan is to divert sediment-rich fresh water from the Mississippi and Atchafalaya Rivers. The freshwater diversion structures are designed to enhance marsh accretion, plant productivity, and freshwater retention (Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1997). In Louisiana, two major diversion structures are currently operating, Caernarvon and Davis Pond. These diversion structures are designed for diverting water and this water contains suspended sediments.

According to Sasser et al. (1995a), the effect of significant sediment introduction into wetlands with floating marshes is unknown. In a study done in the Atchafalaya River-Fourleague Bay system in Louisiana, USA, Holm et al. (2000) state that a gradient of increasing vertical marsh movement and decreasing mineral sediment influence with distance from the river system suggests that the presence of an adjacent sediment source may limit the potential buoyancy of floating marsh substrates. This is an important issue because marsh mat buoyancy depends on the formation of an organic mat almost entirely free of mineral sediments, but on the other hand, mineral sediments supply new nutrients to enhance marsh growth (Sasser et al., 1995a).

The proposed re-introduction of Mississippi River water and sediments into coastal marshes will promote healthy marsh vegetation by providing mineral nutrients for plant growth, and increasing iron content for plant soil, which reduces toxicity of sulfur, a plant toxin (DeLaune et al., 1991). However, it is unknown what the effects of introducing river sediment to a floating marsh might be on the marsh vegetation and mat flotation. The first objective of this study is to evaluate the response of the marsh mat to the addition of Mississippi River sediment in a freshwater thin mat floating marsh. A second objective is to monitor species composition change and growth response of vegetation after sediment is added to the marsh surface.

MATERIALS AND METHODS

Study Area Description

Barataria Basin, Louisiana is located between the recently abandoned Mississippi River channel, Bayou Lafourche, and the current active Mississippi River channel in the Mississippi Delta Plain. Bayou Lafourche was the main channel of the Mississippi River from approximately the second to the twelfth century (Frazier, 1967) (Doyle, 1972). It was dammed in 1904 to control flooding, eliminating a source of sediments and fresh water to the Lafourche Delta (Doyle, 1972).

Two study sites were established in Coastal Louisiana in the Barataria and Terrebonne Basins. The dominant plant at both study sites is *Eleocharis baldwinii*. Both Site 1 and Site 2 are classified as freshwater thin-mat floating marshes (Sasser et al., 1996). Study site 1 is located at Cypress Canal below the Davis Pond Freshwater Diversion Structure in the northern part of Barataria Basin (Figure 1). It is outside of the direct flow from the diversion structure. The coordinates for this site are latitude 29º 51.16´, longitude 90º 18.99´. Study site 2 is located in western Terrebonne Basin at Turtle Bayou (Figure 1) at latitude 29º 34.50´, longitude 91º 04.12´. The Turtle Bayou site is in the northern part of the Terrebonne basin and is isolated from major flows from the Atchafalaya River (Sasser et al., 1995a).

Study Design

In order to reach the study area with minimal disturbance, a boardwalk was built. The 1.0m^2 experimental plots were placed at 1.5 m intervals along the length of the boardwalk. The marsh substrate within the plots was cut around the sides. This was done to reduce the effect from the surrounding untreated, potentially more buoyant, marsh on the vertical movement of the marsh within the plots.

Justification of Methods

Parameters were measured which were appropriate for determining vegetation and soil conditions similar to previous studies. This was done for maximum comparability to those studies. Some variables are emphasized more than others because they were the most useful to my study and previous studies.

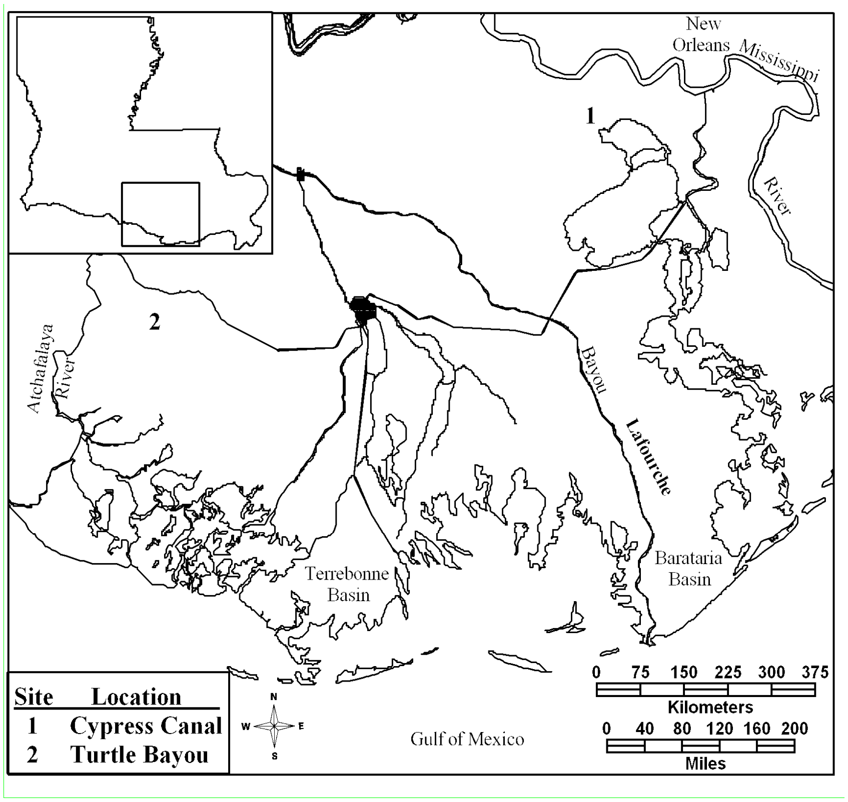

Figure 1. Location map of Sites 1 and 2 in Southern Louisiana. The study sites are located between the Atchafalaya River to the west and the Mississippi River to the east.

Five types of experimental treatments, including controls, were applied at each site. Control 1 (C1) plots were surrounded by exclosures with no sediment added to the plots. Control 2 (C2) plots had no exclosures and no sediment addition to represent the natural system. Sediment treatments were low, medium, and high. A total of 2,000 g (5.57 lbs) of sediment were added for the low sediment treatments (LS) creating a sediment layer of 0.077 cm thick on the marsh surface. Medium sediment (MS) treatments consisted of 7,000 g (19.5 lbs) of sediment added to the surface of the marsh creating a sediment layer of 0.268 cm thick. High sediment (HS) treatments added 17,000 g (47.4 lbs) of sediment to the surface of the marsh createing a sediment layer of 0.651 cm thick. It was calculated that the sediment additions, assuming a soil depth of 30 cm, would achieve the following bulk densities: low (0.05 g/cm^3), medium (0.10 g/cm^3) and high (0.20 g/cm^3). The estimated depths and bulk densities are based on a calculation using the particle density of quartz (2.61 g/cm^3) from DeLaune et al. (1983). Each treatment was replicated four times and established on the thin mat floating marsh at each of the two study areas. C1, LS, MS, and HS plots were surrounded by exclosures to prevent herbivory by nutria, which are abundant in the study areas. Exclosures made from light PVC pipe and plastic coated poultry wire were connected to sleeved pipes that allowed them to move up and down with the water level. This prevented the exclosures from weighing down the mat.

Sediment

In a similar study based in a Louisiana attached salt marsh, DeLaune et al. (1990) used sediments dredged from a basin adjacent to the study site in their study treatments. In this study, I used sediment from the Mississippi River collected from Richfield Riversilt in Baton Rouge, LA containing recently deposited sediments. This soil was collected in 5 gallon buckets and applied semi-dry to the plots.

Sediment Grain Size

A sediment grain size was determined by the settling method (personal communication with Dr. Ronald DeLaune) (Patrick, 1958). For the Richfield Riversilt sediment, sediment grain size percentages were as follows:

Percent Silt = 32.5%, Percent Clay = 22.5%, Percent Sand = 45%

Sediment Nutrients

Sediment samples were also analyzed for nutrients at the Louisiana State University Department of Agronomy’s Soil Testing Laboratory. Soil exchangeable cations were extracted with 1.0 N ammonium acetate and cations in solution were analyzed by Inductively Coupled Plasma Emission Spectrophotometer (ICP). Extractable phosphorous was determined by extracting soil with Bray II extracting solution (0. 1 N HCl and 0.03 N ammonium fluoride) (Olden and Dean 1965). The phosphorous in solution was determined by ICP (Chapman 1965). Organic matter was determined by dip-probe colorimeter (Graham 1948) calibrated against the Walkley-Black method, a wet oxidation method used to determine oxidizable carbon. Moisture content of the sediment was determined and factored into calculations for weights to be added to plots. Results of the sediment nutrient analysis are presented in Table 1 and Table 2.

Nutrient Input Associated with Sediment Addition

Nutrient input associated with addition of the Mississippi River sediment was determined for calcium, magnesium, phosphorus, potassium, sodium, and nitrogen. Percentages of each nutrient available in the sediment were calculated and multiplied by the grams of sediment being added to each treatment plot (LS = 2,000 g, MS = 7,000 g, HS = 17,000 g). The results produced the amount of each of the above nutrients that was added with each sediment treatment addition (Table 3) (Table 4).

Introduced Plant Species

The possibility of introduced plant species occuring within the added sediment material was considered. To find out what plant species may be introduced with the added soil, I performed a greenhouse experiment using the drawdown procedure from van der Valk and Davis (1978). Sediment samples were spread 1 cm thick over the surface of a plastic container containing 3 cm of sterilized soil. Five of these containers were placed in a greenhouse and watered with tap water to keep the surface moist.   Vegetation that grew in the containers was collected, pressed, and identified. All of the species from this seed bank study were identified as upland species (personal communication, Michael Materne, LSU AgCenter).

Vegetation

Species Composition

Species composition was determined for live species before vegetation was dried to calculate aboveground biomass. Species were determined for each site and each treatment type (Table 5).

Aboveground Biomass

The vegetation was characterized at each of the study plots by harvesting aboveground plant biomass at the beginning and end of the growing season. All live and dead vegetation material was removed from 0.10 m^2 sample plots taken from each study plot. These samples were taken from the middle of the plots to avoid edge effect. All live plants were separated by species, dried at 60º C to constant weight, and their dry weights recorded. Dead material was separated into *Eleocharis baldwinii* and other dead material.

Belowground Biomass

To measure belowground biomass, 7.4 cm diameter cores were taken from each study plot to a depth of 15 to 30 cm. This was done at the end of the growing season. Cores were sectioned into 10 cm intervals and separated into live and dead roots. These sections were dried at 60º C to constant weight and these weights were recorded on a dry mass basis.

Plant Tissue Nutrient Content

Nutrient content of the plant tissue and total uptake based on tissue analysis were measured after experiment completion. The plant material was taken to LSU and processed at the Wetlands Biogeochemistry lab. Total element analysis (N, P, K, Ca, Mg, Mn, S, Fe, Na, Zn, B) was performed on plant tissue and soil samples. Samples (0.5g) were digested with HNO_3 and the aliquots analyzed for total elements using ICP procedure.

Carbon and nitrogen content and the C/N ratio in plant tissue were determined using a Carbon-Nitrogen Analyzer. The instrument used in the analysis is a Heraeus CHN-O-Rapid Elemental Analyzer (UIC, Inc., Joliet, IL), which employs a dry combustion technique. The process employed for gas separation is the Pregl-Dumas process (Patterson, 1973). Approximately 50 mg of each sample was weighed into a 12 x 5 mm tin capsule using a Satorius M3P Microbalance (Satorius North America, Inc., Long Island, NY). The capsules were crushed into pellets, which were placed in an auto-sampler and analyzed for carbon and nitrogen.

Bulk Properties

To measure bulk density and percentage organic matter, I collected a 7.4 cm diameter core from each study plot, following the procedure described by Sasser et al. (1995a). I then sectioned each core into 5 cm intervals. Each 5 cm interval was weighed for its wet bulk density and then dried to a constant weight at 60º C to determine dry bulk density and water content. The matter was milled through a #40 mesh and about 1.0 g of each 5 cm interval was burned in a muffle furnace for 3 hr at 550º C. Organic content was measured using the loss-on-ignition procedure (Swarzenski et al., 1991).

Table 1. Total nutrients contained in the Mississippi River sediment.

	Al ppm	B ppm	Ca %	Cu ppm	Fe ppm	Mg %	Mn ppm	P %	K %	Na ppm	S %	Zn ppm
Total	20722.03	9.09	0.51 %	13.68	19564.64	0.48	345.35	0.046	0.29	197.79	0.022	52.95
Organic Matter %	1.129											
Nitrogen %	0.059											
pH	7.890											

Table 2. Extractable nutrients contained in the Mississippi River sediment.

	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm
Extractable	227.19	160.41	2679.80	583.70	33.54

Soil Nutrients

I collected a 7.4 cm diameter core from each study plot for soil nutrient determination. The top 15 cm of each core was sent to the Louisiana State University Department of Agronomy's Soil Testing Laboratory for processing. Soil exchangeable cations were extracted with 1.0 N ammonium acetate and cations in solution were analyzed by ICP. Extractable phosphorous was determined by extracting soil with Bray II extracting solution (0. 1 N HCl and 0.03 N ammonium fluoride) (Olden and Dean 1965). The phosphorous in solution was determined by ICP (Chapman 1965).

Water Depth Measurement

The marsh mat was uniform, or similar in buoyancy, across the study areas. Water level measurements over the mat were taken at each plot in November (Site 1) and September (Site 2) of 2004. This was done to test if sediment addition had any effects on mat flotation. Four measurements were taken from each plot and recorded in cm. For analysis, these measurements were adjusted as follows. Average water depths from Site 1 and Site 2 were determined, and the difference (17.8 cm) between the two found. To adjust the water depth, this difference was subtracted from the site with higher water levels, Site 2.

Analysis

All statistical tests were done using Statistical Analysis System (SAS, 2003) software. Treatments in Analysis of Variance (ANOVA) were the treatments were the five sediment treatments. In the case of belowground biomass, depth was also used as a treatment. Blocks were Site 1 and Site 2. Comparison of sediment additions was done using Least Square Means (LSMeans) with Tukey-adjusted p-values to control the error rate.

Table 3. Total nutrient input associated with each sediment addition treatment type

	Total Nutrients (g/m^2)												
	N	P	K	Cu	Fe	Mg	Mn	B	Ca	S	Na	Zn	Al
Low Sediment	1.18	0.92	5.8	0.027	39.13	5.39	0.69	0.018	10.28	0.44	0.395	0.106	41.44
Medium Sediment	4.13	3.22	20.3	0.096	136.95	34.23	2.415	0.063	35.98	1.54	1.379	0.371	145.05
High Sediment	10.03	7.82	49.3	.233	332.59	83.13	5.865	0.153	87.38	3.74	3.349	0.901	352.27

Table 4. Extractable nutrients associated with each sediment addition treatment type.

	Extractable Nutrients (g/m^2)				
	P	K	Mg	Ca	Na
Low Sediment	0.454	0.32	1.16	5.396	0.067
Medium Sediment	1.59	1.12	4.102	18.88	0.234
High Sediment	3.862	2.72	9.91	45.86	0.569

Table 5. Species composition and biomass (g/m2) by study site and treatment.

Site	Species	C1	C2	LS	MS	HS
1	*Eleocharis baldwinii*	48	48	71	89	122
	Hydrocotyl umbellata	3	6	7	33	18
	Alternanthera philoxeroides	85	125	123	258	258
	Aster subulatus	4				
	Bacopa monerii	45		55	27	
	Cyperus odoratus				1	
	Cyperus polystaches				7	
	Eleocharis rostellata	24				
	Furina pumila			14		
	Galium tinctorium			1		
	Habaneria sp.	2			3	
	Ludwigia sp.	2		4		
	Phyla nodiflora	100	49	102	127	70
	Polygonum punctatum	169	134	68	82	159
	Sacciolepis striata	97	162	28	59	42
	Sagittaria latifolia	21	6	9	3	12
	Scirpus olneyi	1				
	Solidago sp.			8	3	
	Dead Eleocharis baldwinii	133	32	65	96	132
	Other dead material	315	105	176	289	288
2	*Eleocharis baldwinii*	238	155	167	220	232
	Eleocharis flavescens	1	26	3	2	2
	Hydrocotyl umbellata	47	22	35	23	37
	Leersia oryzoides	6				
	Ludwigia leptocarpa	9	30	84		
	Ludwigia oclovalis					121
	Ludwigia peploides	7	9	19	12	16
	Ludwigia sp.		6		1	
	Phyla nodiflora	0	20	30	45	65
	Sacciolepis striata	10	3			
	Unknown grass	12	2	5	10	3
	Utricularia sp.	10	3	6	5	
	Bacopa monnerii	4		8		
	Bidens laevis	14	21	29	43	135
	Alternanthera philoxeroides		5	3		12
	Hydrolea ovata		51			
	Justicia ovata		25			
	Paspalum vaginatum		14			
	Dead Eleocharis baldwinii	214	76	187	143	189
	Other dead material	87	56	142	118	90

RESULTS

Bulk Density

Analysis of variance of the bulk density data showed significance between sediment treatments (p = 0.0005) (Figure 2), but no significance between sites, depth, or sediment*depth interaction. Averaged over the top 25 cm of the mat, bulk density was significantly higher in the high (0.068 g/cm^3) and medium (0.063 g/cm^3) sediment additions than C1 (0.043 g/cm^3), C2 (0.048 g/cm^3), and low (0.044 g/cm^3) sediment additions. The data indicated a trend of increase in bulk density with an increase in sediment addition. Although it was not statistically significant (p = .0526), the data indicated also a change in bulk density by depth. The noticeable changes occurred in the top 5 cm (Figure 3). Control plots showed increasing bulk density with depth. Low sediment addition plots (LS) showed similar bulk density with depth, while medium (MS) and high sediment (HS) treatments showed high bulk density (approximately 0.10 g/cm3) in the top 5 cm with large variation and relatively equal bulk densities below 5 cm depth.

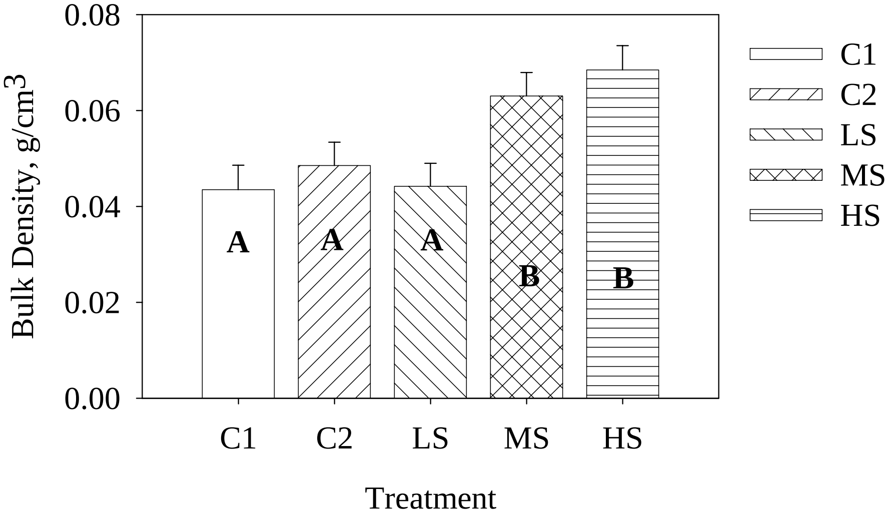

Figure 2. Mean bulk density in the top 25 cm of the two study sites as a function of increasing sediment introduction. Letters on the graph show significant differences using LSMeans with a

Tukey-Kramer adjustment. C1 = control with exclosure, C2 = control with no exclosure, LS = low sediment addition, MS = medium sediment addition, HS = high sediment addition.

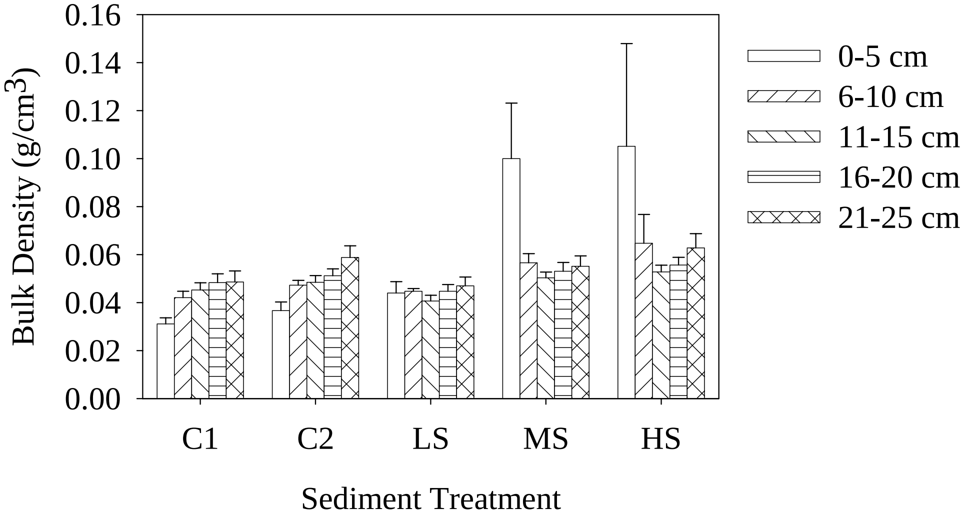

Figure 3. Bulk density in the top 25 cm of the mat as a function of depth. Though not statistically significant, the bulk density increased most in the top 5 cm of the mat with the addition of sediment.

The predicted and average bulk densities for depths of 0 – 10 cm and 0 – 25 cm were measured after the addition of sediment to the study plots. From these measurements, the percent sediment remaining was determined (Table 6).

Table 6. Predicted and average bulk densities measured after the addition of sediment, and percent sediment remaining after application.

	Depth	Control	Low Sediment	Medium Sediment	High Sediment
Average Measured (g/cm^3)	0 - 10	0.0396	0.0447	0.0782	0.0849
	0 - 25	0.0460	0.0442	0.0630	0.0685
Predicted (g/cm^3)	0 - 10	0.0396	0.0592	0.1067	0.1968
	0 - 25	0.0460	0.0538	0.0732	0.1111
% Sediment Remaining	0 - 10		28%	59%	34%
	0 - 25		52%	85%	75%

Organic Matter

Analysis of percent organic matter found significance by site ($p < .0001$), sediment treatment ($p < .0001$), depth ($p < .0001$), and sediment*depth interaction ($p = 0.0008$). Organic matter content at site one (85.20%) was significantly higher than at site two (73.60%) (Figure 4). Percent organic matter of medium and high sediment additions were significantly lower than those of controls 1 and 2 (Figure 4). Percent organic matter in the low sediment treatment was significantly higher than that of medium sediment treatment, but not of high sediment treatment. In the top 25 cm of the mat, there was a sediment*depth interaction. This interaction is due to the decrease in organic matter in the top 5 cm at Site 1 and the top 10 cm at Site 2 with sediment addition (Figure 4). Site 1 percent organic matter values in the top 5 cm were as follows: C1 = 90%, C2 = 89%, LS = 66%, MS = 45%, HS = 55%. Site 2 percent organic matter values for the top 5 cm were C1 = 90%, C2 = 82%, LS = 68%, MS = 52%, HS = 50%. Values for the 6-10 cm levels were C1 = 85%, C2 = 85%, LS = 77%, MS = 75%, and HS = 65%.

Species Composition

Plant species common to both sites included *Eleocharis baldwinii*, *Hydrocotyl umbellata*, *Alternanthera philoxeroides*, *Ludwigia sp*., *Phyla nodiflora*, and *Sacciolepis striata* (Table 5). All of these, except for *Eleocharis* and *Hydrocotyl*, had higher biomass at Site 1 than Site 2. Dominant species at Site 1 were *Eleocharis baldwinii* (HS, 122 g/m^2), *Alternanthera philoxeroides* (MS and HS, 258 g/m^2), *Phyla nodiflora* (MS, 127 g/m^2), *Polygonum punctatum* (C1, 169 g/m^2), and *Sacciolepis striata* (C2, 162 g/m^2). Dominant species at Site 2 included *Eleocharis baldwinii* (C1, 238 g/m^2), *Hydrocotyl umbellata* (C1, 47 g/m^2), *Ludwigia leptocarpa* (LS, 84 g/m^2), *Phyla nodiflora* (HS, 65 g/m^2), and *Bidens laevis* (HS, 135 g/m^2). Species composition at both sites remained the same despite the addition of sediment.

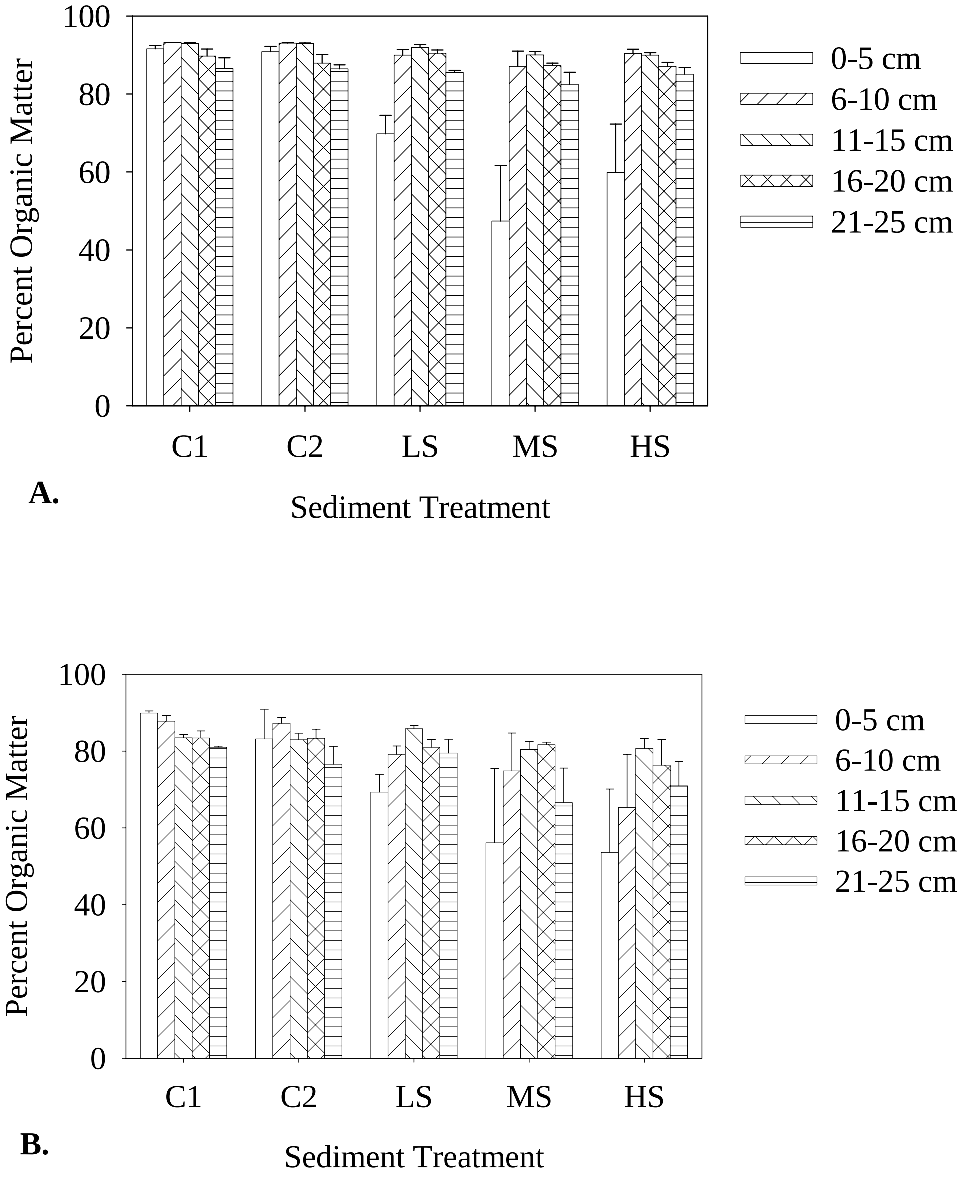

Figure 4. Site comparison showing significant differences in percent organic matter content between sites 1 (A) and 2 (B).

Aboveground Biomass

Live aboveground biomass values were significantly ($p < .0001$) higher at Site 1(C1 = 500g/m^2, C2 = 450 g/m^2, LS = 425 g/m^2, MS = 600 g/m^2, HS = 650 g/m^2) than at Site 2 (C1 = 325 g/m^2, C2 = 250 g/m^2, LS = 260 g/m^2, MS = 350 g/m^2, HS = 425 g/m^2). However, dead aboveground biomass was not significantly different among sites (Figure 5).

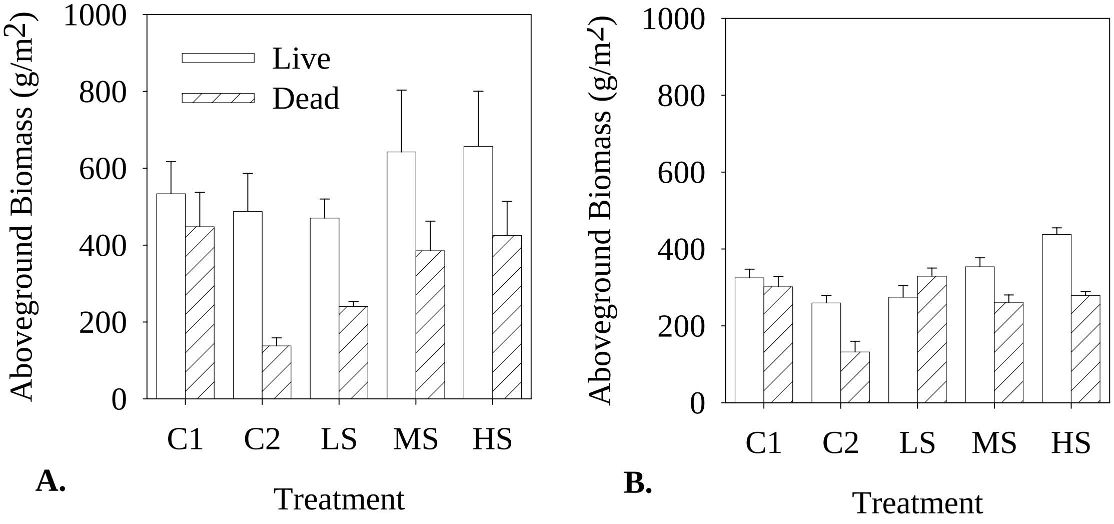

Figure 5. Site comparison of live and dead aboveground biomass. Site 1 (A), Site 2 (B).

Though not statistically significant (p = .1229), a trend of increasing live aboveground biomass with increasing sediment addition was observed (C1 = 429 g/m^2, C2 = 373 g/m^2, LS = 373 g/m^2, MS = 498 g/m^2, HS = 547 g/m^2). Dead aboveground biomass was significantly different among sediment treatments (p = 0.0006) (Figure 6). However, C2 (135 g/m^2) plots, the only grazed treatment, had significantly lower dead aboveground biomass than all other treatments. Dead aboveground biomass of low (285 g/m^2), medium (323 g/m^2), and high (352 g/m^2) sediment treatment plots as well as the C1 plots (374 g/m^2) were not significantly different from each other. When analysis was performed with C2 plots removed, no significant treatment effect was observed. Although not statistically significant, there was a slight trend of increasing dead aboveground biomass with increasing sediment addition.

Species Numbers

The average number of species, live and dead, did not change with addition of sediment. Species numbers were not significantly different by site or by sediment treatment. The high sediment addition had the lowest mean live number of species (6.37), approximately one species less than the other treatments, though it was not statistically significant (Figure 7).

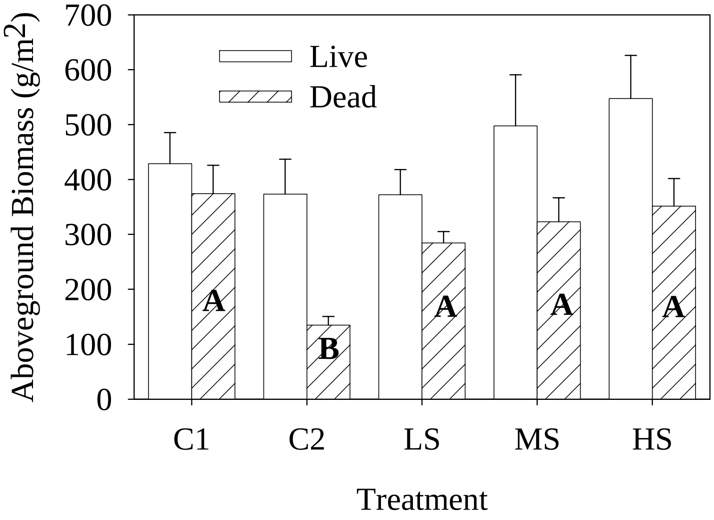

Figure 6. Overall trend using data from both sites of increasing aboveground biomass with increasing sediment addition. No statistically significant differences in live biomass.

Belowground Biomass

Live belowground biomass was statistically significant with depth ($p < .0001$) with greater biomass in the top 10 cm than the 11 – 20 cm depth (Figure 8). The average biomass value for the top 10 cm was 286 g/m^2. The 11 – 20 cm depth average biomass was 49.4 g/m^2. Live belowground biomass was not significant by site, sediment treatment, or sediment*depth interaction (Figure 9).

Dead belowground biomass was statistically significant by site ($p < .0001$) with Site 1 having a significantly greater amount of dead belowground biomass than Site 2 (Figure 10). Dead belowground biomass was also statistically significant by depth ($p = .0110$) with the top 10 cm having higher dead belowground biomass than the 11 – 20 cm depth (Figure 11).

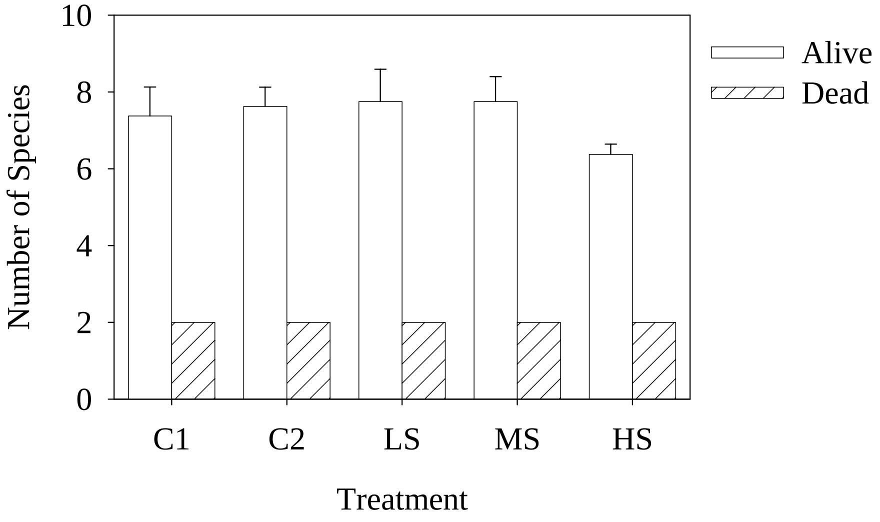

Figure 7. The mean number of species found at sites 1 and 2. It is not significant by site or sediment treatment.

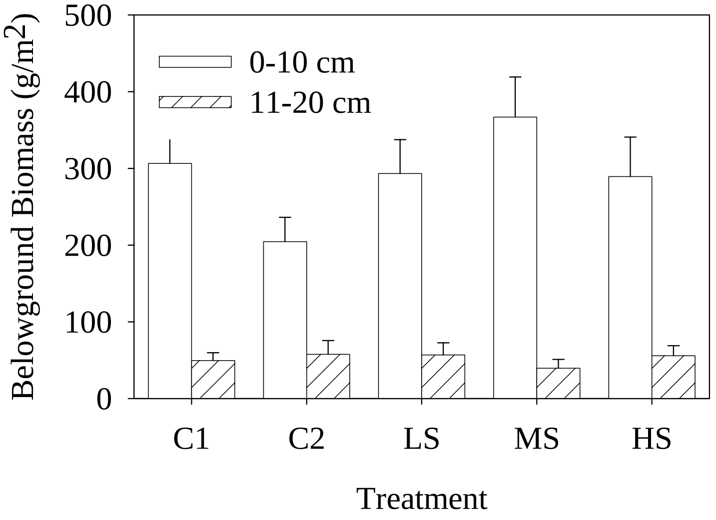

Figure 8. Mean live belowground biomass as a function of depth of mat up to 20 cm. Significant with $p < .0001$.

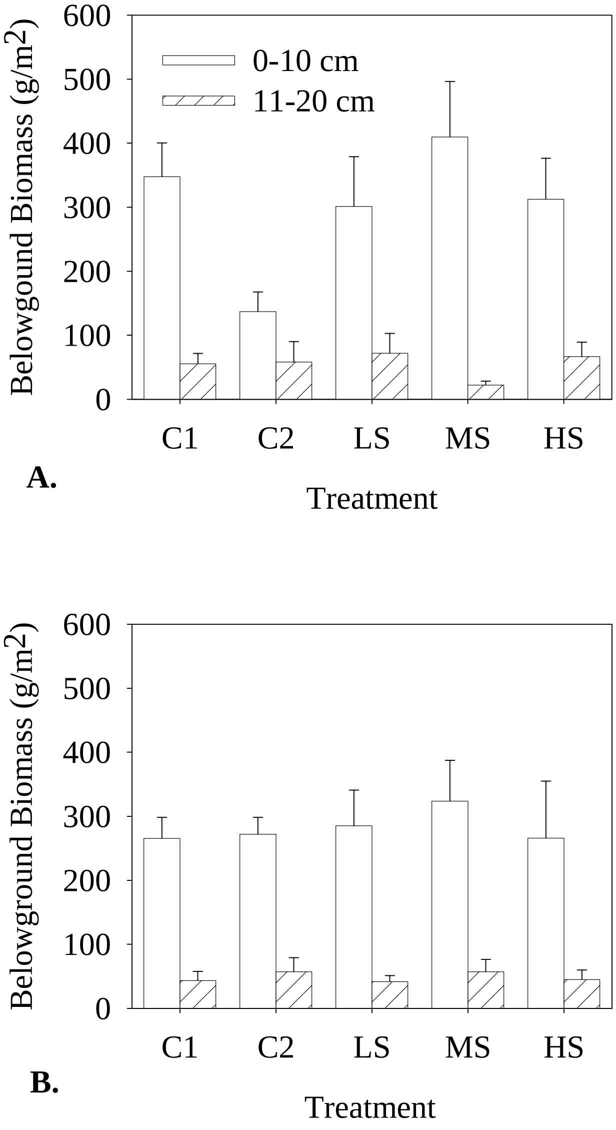

Figure 9. Live belowground biomass as a function of site. There are no statistically significant differences between Site 1 (A) and Site 2 (B).

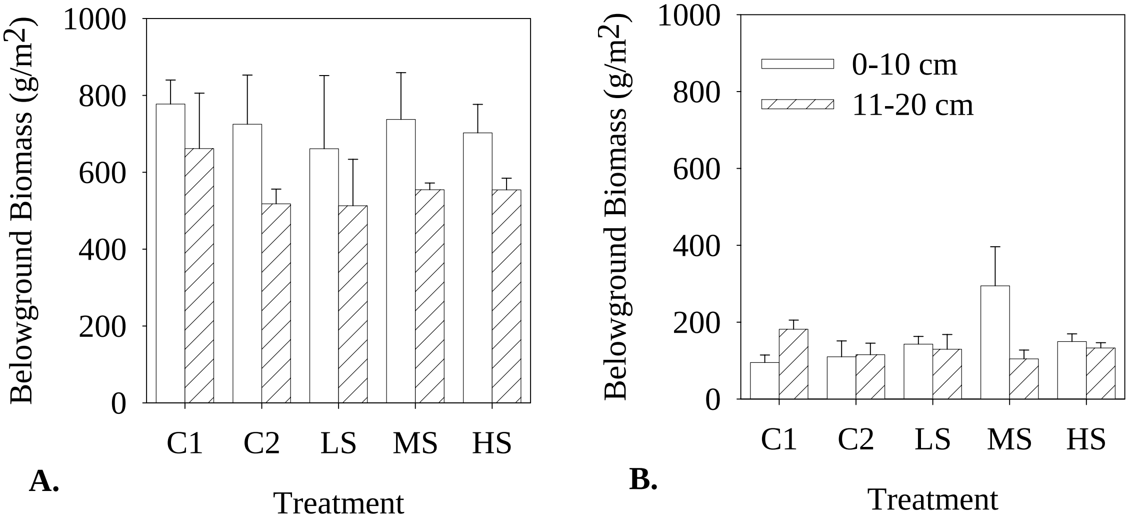

Figure 10. Dead belowground biomass as a function of site. Site 1 (A) is significantly greater than Site 2 (B) ($p < .0001$).

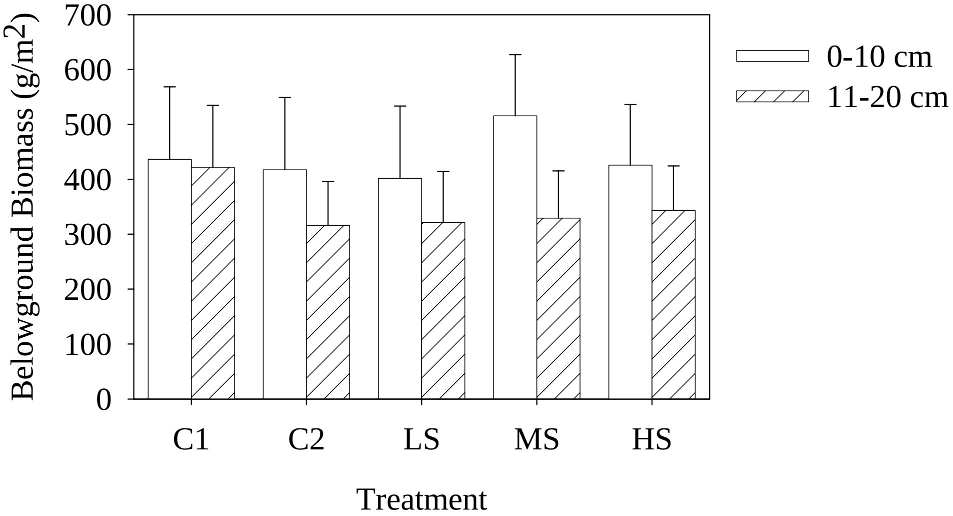

Figure 11. Dead belowground biomass as a function of depth of the mat up to 20 cm. Significant with $p = 0.0110$.

Water Depth Over the Mat

Water depth over the mat was measured in centimeters at each site and the numbers were adjusted to be similar at each site. These measurements were used to determine whether or not the added sediments caused the mat to sink. Mean water depths were C1 = 9.48 cm, C2 = 6.54 cm, LS = 8.49 cm, MS = 8.59 cm, and HS = 9.09 cm. There was a statistically significant impact of sediment treatment on water depth ($p < .0001$). No statically significant differences occurred between treatments C1, LS, MS, and HS. However, C2 treatments had significantly less water over the mat than all other treatments (Figure 12).

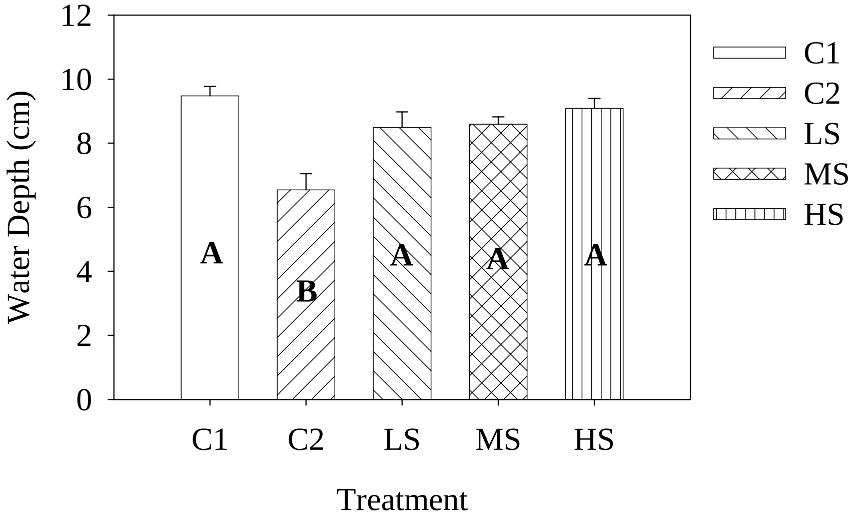

Figure 12. Water depth over the mat as a function of sediment treatment. C2 treatments were significantly lower than those of all other treatments. Letters on the graph show significant differences using LSMeans with a Tukey-Kramer adjustment.

Plant Tissue Nutrients

The added sediment resulted in some increases in nutrient content of *Eleocharis baldwinii* plant tissue. Nutrients statistically significant by treatment were magnesium ($p < .0001$), nitrogen ($p = 0.0098$), and potassium ($p = 0.0070$) (Figure 13). For these three nutrients, plants from the grazed control (C2) had significantly higher concentrations than the un-grazed control (C1) and the sediment treatments (LS, MS, HS). Statistically significant differences of nutrients in *Eleocharis baldwinii* plant tissue were found by site in calcium (p = 0.0003), iron (p < .0001), magnesium (p < .0001), nitrogen (p < .0001), phosphorus (p < .0001), and potassium (p < .0001) (Figure 14).

Magnesium, nitrogen, phosphorus, potassium, and iron content in *Eleocharis baldwinii* plant tissue were all significantly higher at Site 1 than at Site 2 (Table 7). Calcium content of plant tissue was significantly lower at Site 1 (Table 7).

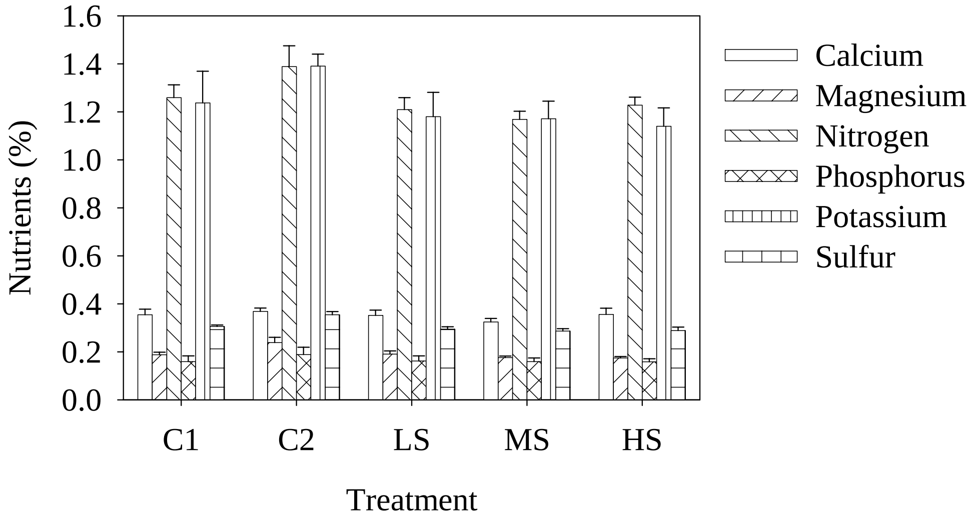

Figure 13. *Eleocharis baldwinii* plant tissue nutrients as a function of sediment treatment. Statistical significance was found in Mg, N, and K.

Table 7. Comparison of *Eleocharis baldwinii* plant tissue nutrient content by site and sediment treatment.

	N*†	P*	K*†	Ca*	Mg*†	S	B	Fe*	Mn	Cu	Zn	Al	Na
Site 1	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
C1	1.362	0.220	1.581	0.301	0.213	0.295	19	2451	772	5	30	36	5711
C2	1.595	0.267	1.478	0.385	0.293	0.362	29	5163	1626	10	38	40	5449
LS	1.296	0.218	1.407	0.315	0.215	0.278	14	1650	686	5	28	41	6066
MS	1.205	0.198	1.358	0.300	0.191	0.260	13	1268	654	4	24	47	5695
HS	1.268	0.190	1.322	0.301	0.183	0.252	14	1902	669	5	25	62	5350
Mean	1.345	0.219	1.429	0.321	0.219	0.289	18	2487	881	6	29	45	5654
Site 2													
C1	1.156	0.097	0.894	0.407	0.162	0.315	11	151	303	12	24	25	5959
C2	1.182	0.110	1.302	0.352	0.183	0.346	10	138	235	5	22	28	5530
LS	1.123	0.103	0.951	0.389	0.165	0.310	11	286	192	12	26	83	4719
MS	1.132	0.119	0.984	0.348	0.159	0.312	10	460	313	8	21	58	5652
HS	1.187	0.126	0.958	0.410	0.164	0.325	12	475	352	11	21	65	5463
Mean	1.156	0.111	1.018	0.381	0.167	0.322	11	302	279	10	23	52	5465

* indicates that values are significantly different by site

† indicates that values are significantly different by sediment treatment

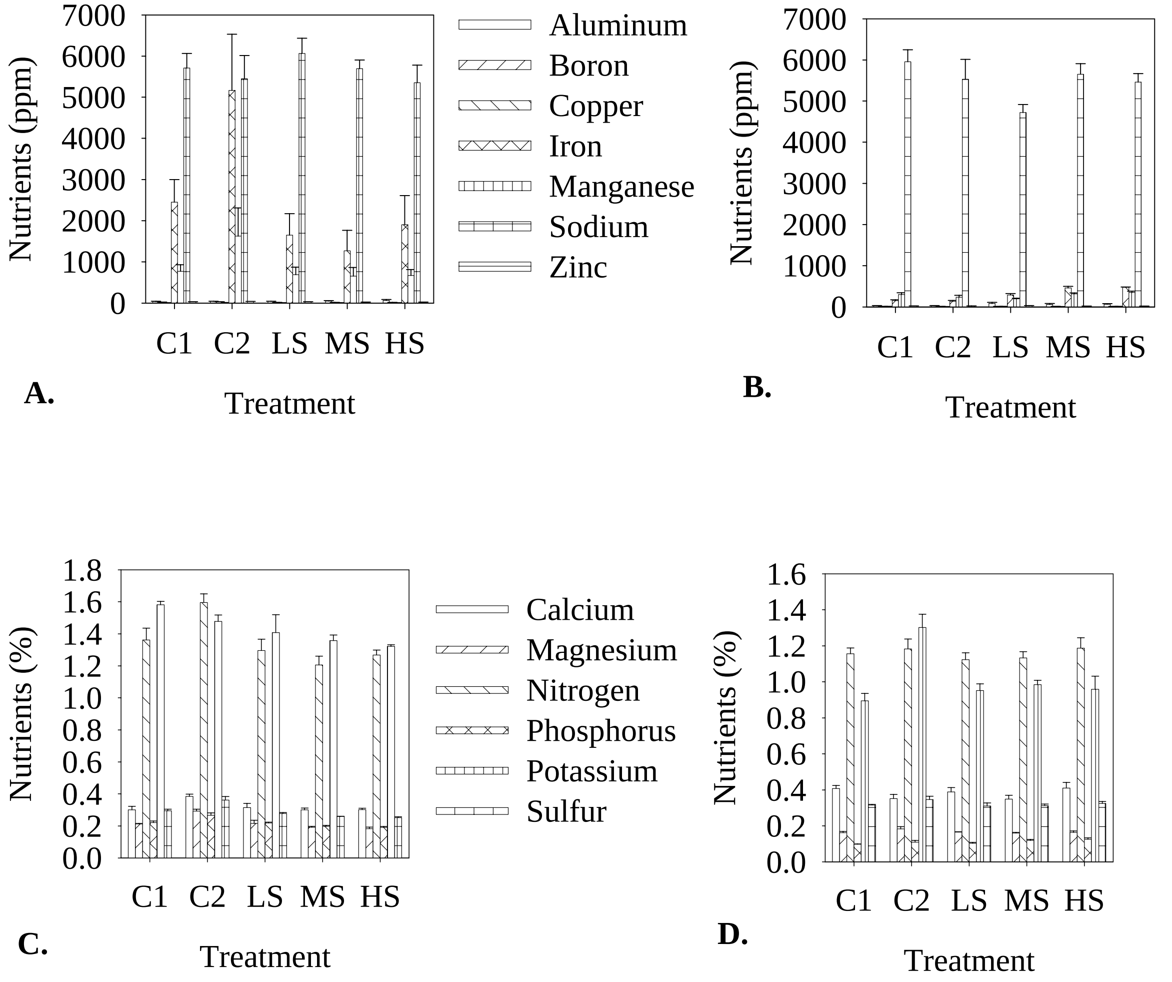

Figure 14. *Eleocharis baldwinii* plant tissue nutrients as a function of site. Site 1 (A and C), Site 2 (B and D).

Soil Nutrients

Primary macronutrients found in the soil were nitrogen, phosphorus, and potassium. Secondary macronutrients included calcium, magnesium, and sulfur. Micronutrients and metals measured included boron, iron, manganese, copper, zinc, aluminum, and sodium. Nitrogen was not significant by site, but was significant by sediment treatment (p = 0.0001). HS treatment plots were significantly lower than C1, C2, and LS plots. Although not significant, there was a decrease in mean nitrogen concentration with highest values at C2 (3.10%) plots, followed by decrease in C1 (3.02%), LS (2.78%), MS (2.40%), and HS (1.76%) (Figure 15).

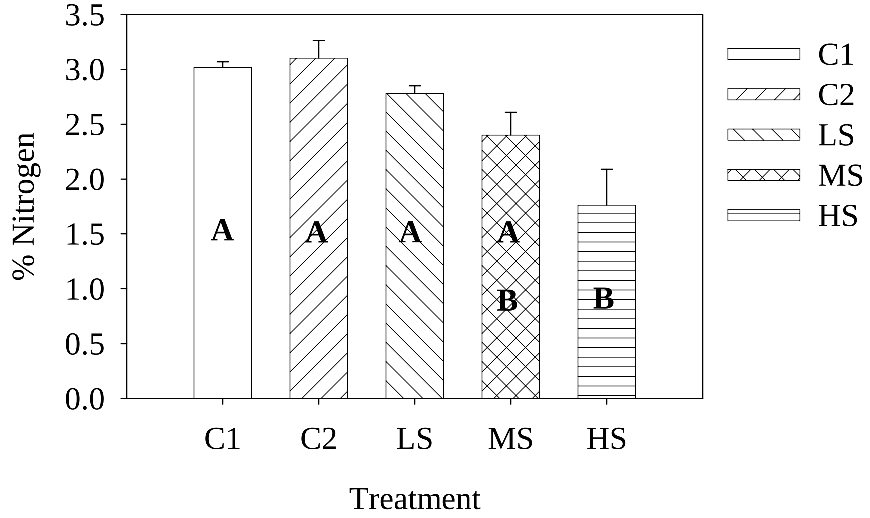

Figure 15. Soil % Nitrogen as a function of sediment treatment. Letters on the graph show significant differences using LSMeans with a Tukey-Kramer adjustment.

Phosphorus, a nutrient associated with minerals, was significant by site (p = 0.0068) and sediment treatment (p = 0.0177). Phosphorus concentrations were significantly higher at Site 1 than at Site 2 (Figure 16). Significant differences between treatments occurred between the control plots (C1 and C2) and HS treatment plots. C2 (33 ppm) plots had the lowest phosphorus means, with a trend of increasing mean phosphorus concentrations as sediment addition increased (C1 = 41 ppm, LS = 61 ppm, MS = 53 ppm, HS = 88 ppm) (Figure 17). Potassium was found to be significant by site (p = 0.0434) but not by sediment treatment (Figures 16 and 17). The mean C2 (381 ppm) potassium concentration was higher than that of the C1 (348 ppm) plots. Potassium mean concentration increased with LS (415 ppm) plots, followed by a non-significant decreasing trend in MS (333 ppm) and HS (299 ppm) treatment plots.

Calcium was significant by site (p = 0.0015) and sediment treatment (p = 0.0240) (Figures 17 and 18). There were significant differences between C2 and HS treatments. A trend of decrease in calcium concentration with an increase in sediment addition occurred, with C2 (7154 ppm) plots having the highest calcium means. Mean values at the other plots were C1 (6115 ppm), LS (6117 ppm), MS (5594 ppm), and HS (4849 ppm). Magnesium was statistically significant by sediment treatment, but not by site (Figures 16 and 17). There was a non-significant trend of decreasing magnesium concentration with increasing sediment addition (C2 = 1671 ppm, C1 = 1474 ppm, LS = 1507 ppm, MS = 1377 ppm, HS = 1214 ppm).

Sodium was not significant by site, but was significant by sediment treatment ($p = 0.0007$) (Figure 17). C1 plots were significantly different from HS plots, and C2 plots were significantly different from MS and HS plots. The highest mean sodium concentration occurred in C2 (1104 ppm) plots. A trend of decrease occurred with lower sodium levels at C1 (956 ppm) plots, and a continual decrease with the addition of sediment in LS (863 ppm), MS (801 ppm), and HS (635 ppm) plots.

Analysis of the soil pH indicated statistical significance by site ($p < .0001$). The mean pH value at Site 1 was 5.4 while the mean pH value at Site 2 was 5.8. However, there was no statistical significance of pH by sediment treatment. Values ranged from 5.11 to 6.16, with little variation occurring with the varying sediment treatments.

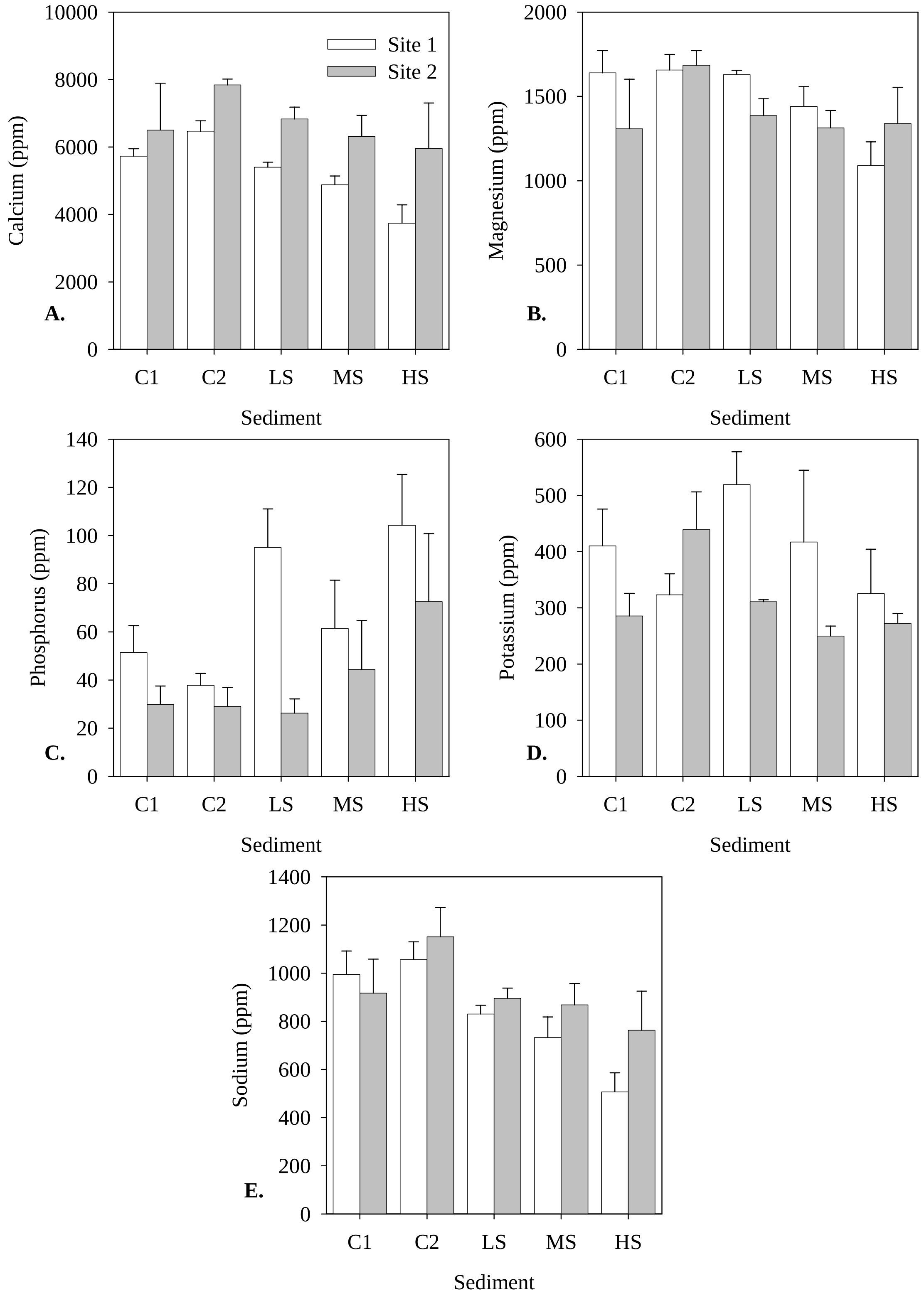

Figure 16. Soil nutrients as a function of site.

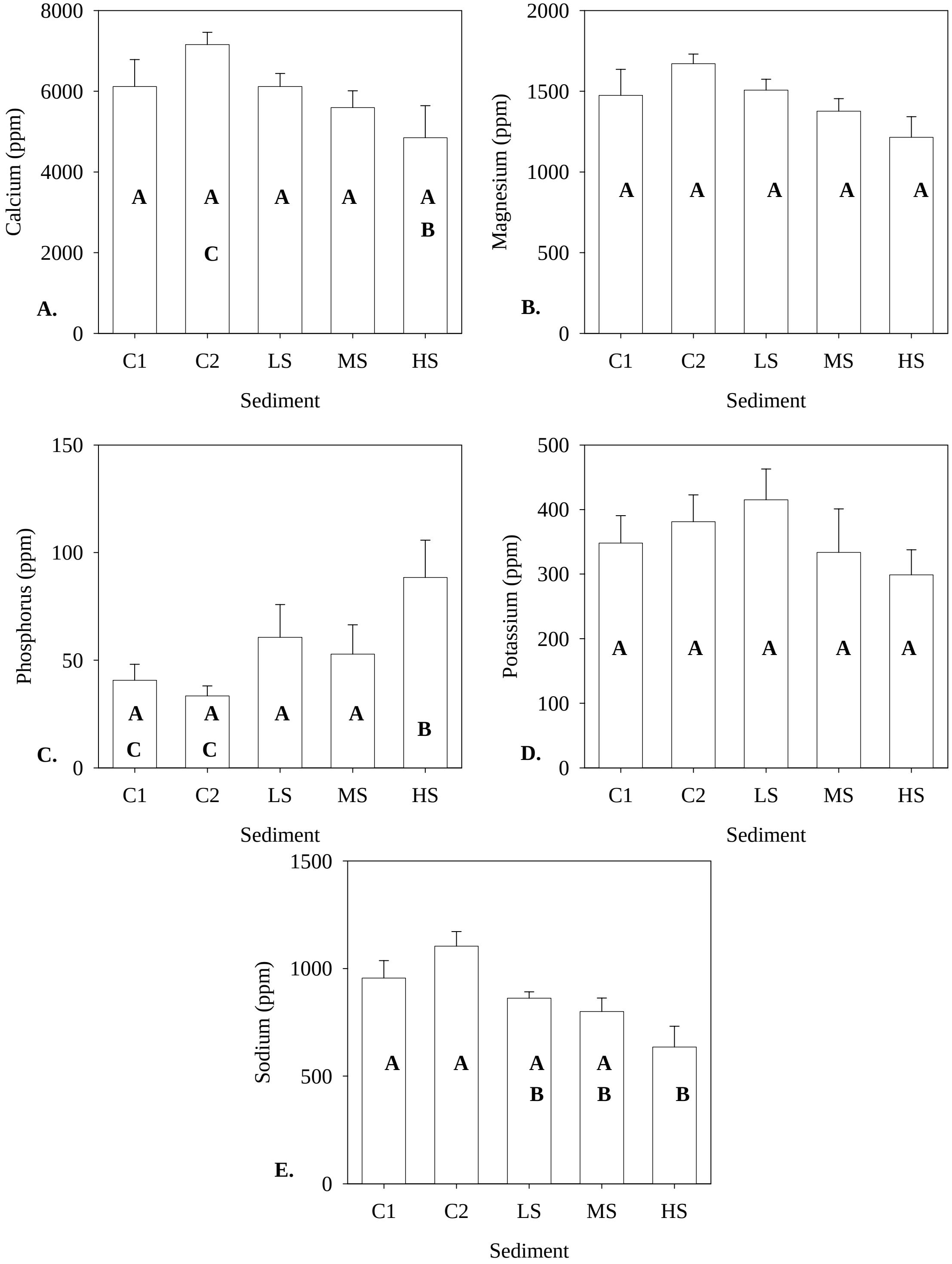

Figure 17. Soil nutrients as a function of sediment treatment.

DISCUSSION

Coastal restoration strategies in the Mississippi River Delta Plain include use of river diversions to reintroduce fresh water and sediments into coastal marshes. Typically, these diversions are located in the upper parts of the coastal basins, where fresh water marshes predominate. These upper basins support large areas of floating marsh.

Sediment deposition in attached coastal marshes adds to the marsh substrate, contributing positively to elevation. Floating marshes do not usually rest on a solid substrate. Instead, the marsh mat floats over a layer of water or fluid decomposing organic matter with the solid soil layer at a depth of 2 m or greater beneath the floating mat. In addition to the issue of the effect of diverted river water on vegetation growth, several issues regarding the fate of sediment introduced into a floating marsh system are of interest. Sediment that remains in the system may move over the marsh mat during periods when water covers the mat. Or, the sediment may sink downward through the mat to make its way to rest on the hard clay layer somewhere below. The sediment may also move in under the mat with water flows or get incorporated into the mat. Mineral sediments deposited or retained within the marsh mat may increase the weight of the mat thereby causing the mat to lose buoyancy and lead to an increase in flooding stress to vegetation growing in the mat.

This thesis addresses two of the questions related to freshwater and sediment introduction into the coastal marsh system. First, what is the response of the freshwater thin-mat floating marsh mat to the addition of sediment? Second, what is the species composition and growth response of vegetation in the marsh after sediment is added to it?

Marsh Mat Response to Sediment Addition

The amount of sediment added to the marsh was 2000, 7000, and 17000 g/m^2. The lowest application rate of 2000 g/m^2 compares to published sediment deposition rates in attached marshes at Caernarvon of about 1148 g/m^2/y (Wheelock, 2003). Using the deposition rates of Caernarvon, my low sediment additions represent just over one year of sediment deposition. At the same rate of deposition, the medium sediment additions (7000 g) would take about 6 years to be deposited, and the high sediment additions (17,000 g) would take about 15 years to be deposited. Though no suspended sediment data were available for the Davis Pond Diversion Structure, it is estimated that the flow through the structure is about 1/8th (0.12) of the flow through the Caernarvon Diversion Structure. Therefore, significantly lower sediment deposition rates are likely in the area of the Davis Pond Diversion compared to those of Caernarvon.

The effect of sediment addition on plant growth was clearly demonstrated in a rooted coastal salt marsh study by DeLaune et al. (1990). He placed Mississippi River sediment at rates of 47,000 g/m^2 and 97,000 g/m^2 in a Louisiana *Spartina alterniflora* attached salt marsh. This resulted in a significant increase in aboveground biomass with the higher rate of sediment addition (DeLaune et al., 1990). The rates were five times higher than the rates used in this floating marsh project.

In the same study, DeLaune et al. (1990) found a significant increase in Fe, P, and Mn content of *Spartina alterniflora* plant tissue taken from attached marsh plots receiving sediment input. He observed no difference in nitrogen content nor did he observe a significant increase in potassium concentration of plant tissue as a result of the sediment addition. In contrast, my results show no changes in Fe, P, and Mn in the *Eleocharis baldwinii* plant tissue collected from my sites.

Mendelssohn and Kuhn studied the addition of hydraulically dredged sediment to a *Spartina alterniflora* dominated attached salt marsh near Venice, Louisiana. The study area was one which exhibited low resilience to disturbance and low vigor (Mendelssohn and Slocum, 2002), and was highly stressed with a limited lifespan. The dredged sediment was added in higher amounts than my study. Treatments included no sediment, trace amounts of sediment, less than 15 cm, 15 – 30 cm, and greater than 30 cm of hydraulically dredged sediment added to the surface of the marsh. Results produced at this attached marsh were similar to those of DeLaune's (DeLaune et al., 1990). Plant height and biomass increased with increasing sediment deposition because of the increase in marsh elevation associated with sediment addition (Mendelssohn and Kuhn, 2003). Bulk densities from the study indicated that mineral matter content was much higher in areas receiving the most sediment. Wetland soils with a high mineral content have a greater ability to take up and sequester nutrients than from organic soils (Mitsch and Gosselink, 2000). Sediment addition in Mendelssohn's study also caused a significant decline in soil organic matter content. Iron and manganese concentrations increased with higher sediment addition, nitrogen concentrations decreased, and phosphorus concentrations increased with sediment addition. A change in species composition was expected at high sediment subsidy levels, but no such change occurred (Mendelssohn and Kuhn, 2003). The authors noted that species composition may still change over time, a possibility that must also be considered in this study.

Sediment introduced into the fresh water thin mat marsh in my study added weight to the marsh mat, as indicated by the increased bulk density. It would be expected that adding sediment to the marsh would increase bulk density and decrease percent organic matter in the marsh substrate. This occurred at both thin mat floating marsh study sites. The average bulk density from the control plots was measured at 0.039 g/cm^3. Average values in plots with sediment addition were 0.044 g/cm^3 (LS), 0.078 g/cm^3 (MS), and 0.084 g/cm^3 (HS). I added sediment to these plots to increase the bulk density of the top 10 cm of the mat to 0.05 g/cm^3 (LS), 0.10 g/cm^3 (MS), and 0.20 g/cm^3. These values are based on literature values of the bulk density of thin-mat floating marshes. Calculations made using the final measurement data produced predictions of bulk density close to these values. The bulk density of plots before sediment was added was assumed to be the same as the average measured from the control plots. Using this and the assumption that all the material would remain in the top 10 cm, I calculated, based on the added volume and density of the sediment, the estimated bulk density of the soils after sediment addition to be 0.059 g/cm^3 (LS), 0.106 g/cm^3 (MS), and 0.196 g/cm^3 (HS). Comparing the estimated bulk density at full retention with the actual measured values shows that some of the material was lost from the top 10 cm.

It was unknown if the sediment would migrate downward through the mat or stay within the mat soil structure. I calculated the bulk density under the assumption that all material stayed in the top 10 cm or in the top 25 cm (Table 6). From these calculations, it appeared that between 28 and 59% of the sediment stayed in the 0 – 10 cm range, between 52 and 82% migrated down to the 25 cm range, and the rest fell through the mat. The rest of the added material was lost below the mat potentially ending up on the hard clay surface below the marsh mat. Because of limited over-marsh water flow and entrapment within the plant material, re-suspension of applied sediments should be minimal.

The sediment added consisted of 22.5% clay, 32.5% silt, and 45% sand. It is noted that the low sediment treatment addition calculations may be less accurate. Such a small addition of sediment may be more difficult to track as the change falls within the normal variation in soil bulk density. Low sediment treatment addition bulk density was not significantly different from the bulk density of the controls.

The percent organic matter at each site was also affected by the sediment additions. Percent organic matter in the plots with sediment additions was significantly lower than the controls, which received no sediment addition. Site 1 had significantly more percent organic matter than Site 2. Differences between sites may be explained by differences in plant productivity and accumulation of vegetation biomass at each site. Site 1 had the highest biomass production as well as the highest percent organic matter.

The measurement of water depth over the mat was important to evaluate the effects of sediment addition on mat buoyancy. This variable provided a measurement of any mat submergence caused by adding the weight of sediments to the floating mat. The introduced sediment had little effect on mat buoyancy. All treatments surrounded by nutria exclosures had no statistically significant differences in water depth over the mat. However, these treatments did have statistically significantly higher depths of water over the mat compared to the C2 open plots with no treatment (2 cm difference). Water depth measurements were taken in September and November, 2004, a time at the end of the growing season when the thin mat marshes float well (Sasser et al., 1996). Exclosures made from light weight materials (see Materials and Methods) were able to move up and down with vertical fluctuations in water level and were expected to have minimal impact on mat flotation.

Taken from the thickness of the whole thin-mat (25 cm), bulk densities in the low, medium, and high sediment addition treatment plots can be compared to bulk densities of floating marshes from the literature (Sasser et al., 1996). The marsh mat bulk densities with the low sediment addition treatment plots (0.044 g/cm^3) were comparable to that of a *Panicum* thick mat marsh (0.049±0.01 g/cm^3), which floats continuously. Medium sediment treatment additions (0.063 g/cm^3) had bulk densities similar to that of a *Panicum* and *Sagittaria* dominated thick mat marsh (0.062±0.003 g/cm^3), which floats damped and sometimes floats submerged. Those plots with high sediment treatment additions (0.068 g/cm^3) had bulk densities comparable to that of a *Sagittaria* thick mat marsh (0.066±0.011 g/cm^3), which is a seasonally floating marsh, usually floating in the summer and not the winter. None of my treatment plots reached the bulk density of a *Spartina patens* non-floating marsh, which has the bulk density of 0.160±0.006 g/cm^3 and is non-floating.

Vegetation Response to Sediment Addition

At the end of the growing season, live aboveground biomass was significantly higher at Site 1 than at Site 2, as was dead belowground biomass. Previous data indicate that this relationship is typical for these two sites. In October 1993, aboveground biomass at Site 1 was measured as about 400 g/m^2 (Sasser et al., 1994). Total live biomass measured at Site 2 in September 1990 was 129 g/m^2 (Sasser et al., 1995a). Although these data are from different years, they provide additional data that help explain the higher organic matter at Site 1; more biomass produces more organic matter. Species composition may also explain the site differences. Some species at Site 1 have larger growth form than those at Site 2. The trend of increasing live and dead aboveground biomass in L, M, and H sediment addition plots (though not significant) suggests that sediment addition may contribute to plant growth in the thin mat floating marsh, is reported by DeLaune et al.(1990) and Mendelssohn & Kuhn (2003) for attached marshes.

Nitrogen and potassium, two primary macronutrients, were found to be significantly higher in plant tissues from the C2 open treatment plots, but were not affected by the addition of sediment. Table 8 provides information for a comparison of the macronutrients (N, P, K) at Sites 1 and 2 to sufficiency values found in the Plant Nutrition Manual (1998). This table gives a perspective of how nutrient levels in *Eleocharis baldwinii* compare to those in agricultural crop plants. At Sites 1 and 2, *Eleocharis* plant tissue nitrogen is approximately half of that observed in healthy agricultural crops. At Site 1, phosphorus and potassium are approaching the minimum sufficiency value of agricultural crops. Sediment additions at Site 2 increased *Eleocharis* plant tissue phosphorus levels, but these levels remain substantially below the minimum sufficiency value level for phosphorus in agricultural crops. Potassium levels are unaffected by the addition of sediment and are also below the minimum sufficiency value level for potassium in agricultural crops. Nutrients were a component of the sediment addition (Table 1 and Table 2) however the added nutrients did not seem to have been taken up by *Eleocharis baldwinii* plants, as nutrient levels did not increase with sediment addition (Table 8).

Various limitations of measuring plant tissue nutrients in this study need to be addressed. The only plant tissue analyzed for this experiment was that of *Eleocharis baldwinii*. It is unknown if the other plants growing in the marsh area take up more or less nutrients than *Eleocharis*. One growing season may not be long enough to measure the effects of the nutrient additions, especially with respect to competition among different plant species. Therefore, the effects of the increased nutrients in the system on the plants may be different in the long term.

Another possible limitation is that one growing season may not reflect effects on species composition related to an increase in sediment and nutrients. Finally, relative to diversions, this study only looks at nutrients associated with river sediment addition and does not look at the dissolved nutrients in the diversion waters.

Table 8. Comparison of N, P, and K plant tissue sufficiency values (Plant Nutrition Manual, 1998) vs. Site 1 and Site 2 values.

		N	P	K
Sufficiency Value		2.50 - 3.50 %	0.20 - 0.40 %	1.50 - 3.00 %
Site 1	C1	1.362	0.220	1.581
	C2	1.595	0.267	1.478
	LS	1.296	0.218	1.407
	MS	1.205	0.198	1.358
	HS	1.268	0.190	1.322
Site 2	C1	1.156	0.097	0.894
	C2	1.182	0.110	1.302
	LS	1.123	0.103	0.951
	MS	1.132	0.119	0.984
	HS	1.187	0.126	0.958

Similar to the plant tissue nutrients, most significant differences in soil nutrients were found only between the open control plots (C2), which were often the highest or lowest values with these nutrient concentrations. Trends of increase and decrease occurred in phosphorus and nitrogen, but these were non-significant and do not show that the nutrient content of the soil was affected positively or negatively by the addition of sediment. Phosphorus can be expected to increase with increased sediment addition because phosphorus is bound to mineral particles. Site differences can be attributed to the differences in plant composition and possibly water sources.

Plots receiving the high sediment addition treatment revealed a mean number of species of one species less than other treatment plots, a non-significant difference. Therefore, I conclude that the addition of Mississippi River sediment did not increase or decrease the number or types of species occurring at the study sites. No new plants appeared in the study plots after sediment was added. This indicates that none of the seeds added with the river sediment were able to germinate and grow in the floating marsh environment. (The seeds available in the sediment were evaluated and consisted of all upland species [see Materials and Methods] [Mike Materne, personal communication, LSU AgCenter]).

Conclusions

Overall, several main conclusions can be made about this study. The addition of sediment to the surface of the thin-mat floating marsh increased the bulk density in the marsh mat. Some of the sediment filtered through the mat, but the majority remained within the mat, which is about 25 cm thick. The increase in mineral sediment to the floating marsh mat is reflected by a lower % organic matter in the marsh mat. Mat buoyancy was not significantly affected by adding sediment to the floating marsh mat. Vegetation species composition after one growing season was not affected by the addition of sediment to the marsh mat. Also, the sediment did not introduce any new species to the marsh. In terms of vegetative growth response, aboveground and belowground biomass were not significantly affected by the addition of mineral sediment and its associated nutrients.

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