Use of sediment amendment to rehabilitate sinking baldcypress swamps in coastal forests, Louisiana: 2. soil characteristics

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Abstract

Amendments of sediment from dredging activities have played an important role in raising the elevation of sinking coastal wetlands. Nevertheless, the usage of sediment amendments to rehabilitate coastal baldcypress (*Taxodium distichum*) swamps is untested, particularly with regard to the biogeochemical properties of sediment from dredging activities, which covers the original surface soil after application. This study compared the soil characteristics of coastal swamps treated with sediment amendments in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve in treatment sites on Treasure Island with those in natural swamps. The sandy sediment amendments used in the coastal forests had different soil texture and characteristics than the more organic soils of the natural swamps. Three years after the application of these sediments on the coastal swamp of Treasure Island, dewatering and compaction of the sediment had occurred but the sediment still had high salinity and bulk density, and low organic matter content. For the natural swamps, percent organic matter decreased with depth to 20 cm; however, in the sediment amended swamps, the percent organic matter was low throughout the soil column (mean percent organic matter = 4.1% ± 0.5%). Ultimately, organic matter is a key factor in the biogeochemical properties of soils with respect to ion immobilization and water holding capacity. The future soil characteristics of the coastal swamps treated with sediment amendments are likely to depend on the ability of in-situ vegetation to produce organic matter. The two sediment amended swamps differed from each other in that Site 1 had a higher elevation (mean = 25 cm higher) and drier soil than Site 2. The effects of sediment in coastal forested wetlands require separate consideration from studies of salt marshes, e.g., the weight of the sediment might damage tree roots, or the amendments might influence soil stability during storms in a different way.

Generally, this study suggested that shallower depths of sediment are more likely to yield environments beneficial to these sinking baldcypress swamps in coastal Louisiana.

Key words: baldcypress swamp; Barataria; coastal wetland; dredging; Jean Lafitte; soil development; *Taxodium distichum*; wetland rehabilitation

Introduction

The ecosystem functions of many natural wetlands along the Gulf Coast of the U.S. have become degraded by subsidence and flooding due to the withdrawal of groundwater, oil and gas, as well as sea level rise (Delaney et al. 2000), interference of flood flow across wetlands (Boesch et al. 1994), Holocene sediment compaction (Törnqvist et al. 2009) and movement of earthquake faults (Dokka 2006). Many coastal swamp forests of baldcypress (*Taxodium distichum)* are becoming waterlogged because of sea level rise (Conner and Brody 1989), while rehabilitation efforts for coastal salt marsh sometimes have raised elevations using sediment amendments from dredge activities (Delaney et al. 2000). In the U.S., sediment is available for rehabilitation projects from navigation dredging, but the majority of this material is discharged into other water bodies (Mitsch and Gosselink 2007, Lewis 1999). Because managers struggle to maintain increasingly degraded coastal swamps, they have asked whether applications of sediment from dredge activities can successfully rehabilitate these swamps by increasing elevation and restoring less flooded soil conditions.

The vegetation of coastal salt marshes often grows more vigorously in less flooded conditions following the placement of dredged sediment (DeLaune et al. 1990, Mendelssohn and Kuhn 2003). For example, saltmarsh cordgrass (*Spartina alterniflora*) grows 2 to3 times faster after an application of sediment (DeLaune et al. 1990, Ford et al. 1999, Slocum et al. 2005). Plant growth may also cause an increase in elevation; one year after applying 23 mm of sediment, the elevation of a site had increased by 62 mm because of root production (Ford et al. 1999). In deteriorating salt marshes, reinvigorated plants can have an important role in maintaining elevation (Mendelssohn and Kuhn 2003). While the effects of sediment amendments on coastal baldcypress swamps is largely untested, in general, less flooded

conditions improve the survival, production, and/or regeneration of swamp tree species (Middleton and McKee 2005, Middleton 1999). Therefore, interest is growing in whether or not sediment amendment can have any beneficial effects on the rehabilitation of sinking coastal swamps, particularly from the perspective of improving soil conditions for wetland biota.

Sediment amendment could mimic natural disturbances such as hurricanes, which deposit sediments and raise the elevation of certain coastal wetland types (Nyman et al. 1995, Turner et al. 2006). In addition, many swamps are cut off from riverways by levees, and such reengineering can cause changes in hydrology and sedimentation patterns (Middleton 1999). Nevertheless, created salt marshes treated with sediment amendments may never attain certain soil states similar to natural wetlands, e.g., soil organic matter (Craft et al. 1999, Streever 2000). Baldcypress swamps treated with sediment amendments might increase in salinity if the amendment materials were salty; salinity affects the bacterial community of baldcypress swamps, and decreases enzyme activity related to P and N cycling (Jackson and Vallaire 2009). Little is known about the effects of sediment amendment on soil biogeochemical processes in coastal wetlands in general, and baldcypress swamps in particular.

Our objectives were to compare the soil characteristics and environments of coastal baldcypress swamps with and without sediment amendment, so that baseline information will be available to managers seeking to design more effective management strategies for degraded coastal swamps. We compared the soil characteristics of baldcypress swamps treated with sediments from dredging activities versus untreated natural swamps. Specifically, we tested the hypotheses that organic matter level in the soil would be lower,

and that bulk density and mineral content would be higher in sediment amended versus natural baldcypress swamps. We predicted that without sediment additions elevations would become lower over time in these natural coastal swamps.

Study Site

Study Site Description

Baldcypress swamps were studied in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve (NHP&P) USA in the coastal zone of Louisiana. Two swamp sites on Treasure Island (Site 1 and 2), which lie along the Bayou Segnette Waterway were treated with sediment amendments starting in January 2007 (sediment depth in June 2007: Site 1 and 2: 0.89 ± 0.005 vs. 0.69 ± 0.004 cm, respectively). The sediments were removed during the dredging of the adjacent waterway of Bayou Segnette, and reapplied to the adjacent swamps on the other side of a levee along the waterway (David Muir, personal communication). These sediment amended forests were compared to two long-term research sites along Bayou des Familles in the national park (natural swamps: Education Center Spur (ECS) and Education Center Parking Lot (ECP). Within each site, 5 plots were chosen randomly at 25 m intervals along a transect and marked with a stake.

These coastal swamps are affected by tides, which are controlled primarily by offshore winds. The coastal swamps in this study lie off of spoil banks of the waterways, and transition into the floating marsh along the edges of Lake Salvador. The dominant species in these swamps include baldcypress, water tupelo (*Nyssa aquatica*), swamp red maple (*Acer rubrum* var. *drummondii*), pumpkin ash (*Fraxinus profunda*), and palmetto (*Sabal minor*) (Denslow and Battaglia 2002).

Methods

Elevation Survey. Two Surface Elevation Table (SET) monuments were established at each of two sites in natural and sediment amended swamps in December 2006, before the sediment was applied to Treasure Island in January 2007 (total of 8 SETs). Relative elevations were measured from these fixed monuments using a measurement arm with nine pins set in four directions. The actual elevations of sediment in the plots were determined relative to these fixed SET monuments in January 2010 with a Trimble R8 GNSS dual frequency receiver. Elevation estimates were corrected using elevation control points within Continuously Operating Reference Stations (CORS) using the LSU Gulfnet Real-time Network (Uncertainty = 1- 5 cm; Center for Geoinformatics 2006), and an established benchmark (Crown Point Industrial, JPW112B, south of Lafitte, Louisiana). The coastal region is subsiding at a rate of 4-5 ± 2 mm yr^{-1}, due to sediment and water loading (Shinkle and Dokka 2004). The final depth of the dredge material in the swamps was approximately 45 cm or more in the study area, based on observations of sediment depth at staff gauges (Nancy Walters, personal communication).

Soil characterization. Using a Russian peat corer, soil cores were extracted to a depth of 50 cm directly adjacent to each plot along the study transects (i.e., 5 cores per site; see Study Site above). The cores were extracted in December 2006 in the two natural forests and in September 2008 in the two sediment amended swamps (after sediment application). Bulk density was based on the volume of the peat corer and calculated as the dry soil weight (g) divided by the dry soil sample volume (cm^3) (Brady and Weil 2000).

More detailed soil analysis was conducted in the sediment amended swamps with an additional core of 20 cm depth for soil texture in December 2008. Soil samples were photographed, separated into 10 cm increments, placed separately into bags, and transported to the lab. Soil cores were refrigerated until processed.

Soil analysis included percent organic matter, percent mineral matter, bulk density (both forest types), and soil pH, salinity, color and texture (sediment amended swamps only). For soil water content and organic matter, a sub-sample from each soil segment was weighed (wet weight), dried at 105 °C, weighed again, ashed at 450 °C, and weighed a final time. The micro-pipette method was used to determine soil texture (Burt et al. 1993) with three replicates. Soil samples were tested for salinity using a YSI EC 300 probe with two replicates. Soil pH was measured using a HI99121 portable pH meter with 10 g soil and 25 ml of soil preparation solution of HI7051. Before measuring, the soil was mixed for 30 seconds, allowed to settle for 5 minutes, and mixed again. Soil profile color was determined using a Munsell soil color chart (Munsell Color 2000).

Statistical Analysis

Percent organic matter, percent mineral content, and bulk density of the soil were compared in natural and sediment amended swamps using a split-plot design with the ANOVA model including the main effects of forest type, depth, the interaction of forest type x depth with forest type nested by site. Additional comparisons were made of soil in Site 1 versus Site 2 of the sediment amended swamps with the main effects of site, depth, and the interaction of swamp type x depth. Regression analysis was used to examine percent organic matter versus silt content of the sediment amended swamps using all depths collected in 2008. Sediment

elevation over time was compared at each SET using a mean of the 9 pins for each of four directions using ANOVA with the main effects of swamp type x time. Data were appropriately transformed to meet assumptions of ANOVA. One-degree-of-freedom contrasts were made of comparisons of interest. All statistical analysis were conducted using JMP SAS (2007).

Results

Sediment Characterization. The pattern of percent organic matter differed by depth in these forest types (i.e., swamp type x depth interaction: Table 1a, Figure 2a). For the natural swamps, percent organic matter decreased with depth to 20 cm; however, in the sediment amended swamps, the percent organic matter was low throughout the soil column (mean percent organic matter = 4.1% ± 0.5%). Soils from all depths in sediment amended swamps and the natural swamps below 20 cm depth had lower percent organic matter than the upper layers of soil from the natural swamp (0 to 20 cm; $t = 19.4$, $p < 0.0001$; Figure 2a). Percent organic matter and percent mineral content additively comprise the total percent dry soil weight. Therefore, in the soil of the sediment amended swamps, because percent organic matter was low, the mineral content was high (mean percent mineral content = 95.9% ± 0.5%; Figure 2b). The pattern of soil bulk density differed across depths in these swamp types (i.e., swamp type x depth interaction: Table 1b, Figure 2c). The natural swamps increased in bulk density at 30- 50 cm depth, while at shallower depths and in sediment amended swamp the soil bulk density was lower ($t = 7.0$, $p < 0.0001$; Figure 2c). The mean bulk density of the sediment amended swamp was the same at all depths (0.31 ± 0.02; p >

0.05; Table 2 and Figure 2d). When soils from sediment amended swamps were examined separately, the percent organic matter content increased linearly with the percent silt content ($r^2 = 0.37$, $P = 0.0022$; Figure 2d).

Sediment Elevation Change. Before the sediment amendments were applied in January-March 2007, the mean elevation of the natural swamp was lower than the sediment amended swamp (December 2006: 0.093 ± 0.002 m asl vs. 0.180 ± 0.006 m asl (above sea level); t = 2.8, $P = 0.0055$; Figure 3). In June 2007 after the sediment was applied, the mean sediment depth was 1.076 ± 0.009 and 0.789 ± 0.004 m asl at Site 1 and Site 2, respectively ($t = 35.2$, $p < 0.0001$) but the exact depth immediately after application is unknown. Approximately three years after sediment application (December 2009), the elevation still was higher in the sediment amended than in the natural swamp (0.408 ± 0.008 m asl vs. 0.017 ± 0.007 m asl, respectively; $t = 12.68$, $p < 0.0001$). From 2006 to 2010, the elevation of the natural swamp decreased (0.093 ± 0.002 m asl vs. -0.028 ± 0.008 m asl, respectively; $t = 4.61$, $p < 0.0001$).

Detailed Characterization of Sediment used for Amendment. A more detailed characterization of the soil in the sediment amended swamp was done in December 2008. The surface soil (0-50 cm) of these swamps was mainly composed of silt and sand, and the textural class was silt loam and sandy loam (Table 2). Visually, sand and silt layers were evident in the dredge spoil (Figure 4). From the surface to deeper depths, the dredge soil color changed from the dark brown to gray (Table 4) with a matrix Chroma 2 or less (Munsell Color 2000). Salinity in the dredge spoil ranged from 0.1 to 0.7 ppt, and pH from

4.5 to 6.5. By December 2008, the dredge had dewatered and compressed, with a distinct zone of demarcation between the sediment amendment and natural soil at a depth of 20-30 cm. The characteristics of sediments from Site 1 and Site 2 did not differ from each other with respect to depth for soil salinity, pH, bulk density, or soil texture (% clay, sand and silt). Site 1 had lower percent water content near the soil surface (0-10 cm) of sediment, whereas Site 2 was wetter 10-20 cm beneath the surface (i.e., site x depth interaction; Table 1). Soil organic matter varied by depth in Site 1 versus Site 2, with lower organic matter on the surface 0-10 cm in Site 1, and higher organic matter at 10-20 cm in Site 2 (site x depth interaction; Table 1).

Discussion

Sediment amendment can cause biogeochemical and physical changes in wetland environments related to flooding regime, oxygenation, soil particle size, soil strength, and soil nutrient status. Flooding regime and oxygenation levels change because sediment placement increases site elevation (Figure 4), which reduces flood stress to vegetation (Webb et al. 1995, Carpenter et al. 2007). Because sediment amendment increases elevation, the practice can stimulate the growth of stressed vegetation in salt marshes (DeLaune et al. 1990, Pezeshki et al. 1992, Reed and Cahoon 1992, Ford et al. 1999, Mendelssohn and Kuhn 2003, Slocum et al. 2005, Shrift et al. 2008); however, little study has been made of the potential of sediment application to improve the soil conditions of degraded baldcypress swamps along coasts (Terri Jordan, Edward Creef and Linda Mathies, U.S. Army Corps of Engineers, *personal communications*). This study allows a unique opportunity to examine the effects of

sediment application on the soil environment of baldcypress swamps, particularly with respect to biogeochemical and physical processes.

We compared several soil characteristics related to biogeochemical function in these two swamps treated with sediment amendments with natural baldcypress swamps. Any reduction in flooding related to increased elevation with sediment amendment could cause biogeochemical changes (Delaune et al. 1983, Poach and Faulkner 2007). Notably, the elevation above the pre-placement elevation of baldcypress swamps greatly increased (June 2007: Site 1 and 2: 89 and 69 cm, respectively), while in keeping with our expectation, the elevation in the natural swamp was sinking (Figure 3). The amount of sediment amendment placed on the Treasure Island swamp in our study sites was much deeper than typically used on salt marshes, e.g., Ford et al. (1999) reported post-placement elevations of 2.3 cm after sediment amendment in a remediation project in a salt marsh near Venice, Louisiana.

Beyond elevation, other soil characteristics can influence the biogeochemical function of wetlands. For example, if the grain size of the applied sediment was different than that of the soil in the baldcypress swamp, this difference could have created an altered environment for vegetation, particularly as related to water holding capacity. The grain size of the soil in sediment amended wetlands is dictated by the source of the sediment, and has been identified as one of the main contributing factors to differences in biological function between natural and sediment amended wetlands (Streever 2000). Our study found that the sediment placed on Treasure Island of Jean Lafitte NHP&P was more sandy than typical coastal swamp peat.

We examined the sediment characteristics of other amendment projects, and discovered that a variety of sediment is used, and that the type of sediment is identified as a key factor in the success of the project. For example, sandy sediment with a texture similar to that of

bedload sediment was identified as the main difference between created and natural wetlands in the Atchafalaya Delta of Louisiana (Poach and Faulkner 2007). Both the created and natural freshwater wetlands of this delta are a mix of black willow, dotted smartweed (*Polygonum punctatum*), and mudflat vegetation. Nearby, the soils of salt marshes created with sediment near Lake Calcasieau, Louisiana had less than 1% sand (Edwards and Proffitt 2003). The sediment used in our Treasure Island sites was of sand (range: 37-58%; Table 1), silt (range: 42-59%; Table 1), and with a very low percentage of clay (range: 2-5% clay; Table 1). Coarse soils such as sand sorb less nutrients than fine soils, so that sandy soils often have less available nutrients than other soil types (Brady and Weil 1996). Sediment with high sand content has less phosphorus content than sediment with less sand, e.g. sandy bedload sediment has lower iron- and aluminum-bound phosphorus, reductant-soluble phosphorus, and total phosphorus, so that sandy amendments may contribute to phosphorus-limited conditions in a created wetland (Poach and Faulkner 2007). Sandy soils support the growth of black willow over baldcypress at elevations above flooding (Day et al. 2006), and this could be a factor in vegetation establishment in forested swamps treated with sediment amendments. The sediment amended swamps on Treasure Island had a proliferation of black willow and Drummond's red maple after the application of sediment (Middleton and Jiang accepted). In addition to soil texture differences, the pore water salinities of the sediment amended were higher than those of the natural swamps (3.4 vs. 0.7 ppt, respectively; Middleton and Jiang accepted), but we do not know if the sediment placement influenced salinity in these swamps. Considering textural and salinity differences of typical sediment amendments with peaty soils in coastal baldcypress swamps, the best opportunities to raise

elevations in coastal wetlands may be in the salt tolerant types including brackish marsh, salt marsh, and mangrove.

Sediment amendment changes the nature of coastal salt marshes with respect to soil characteristics such as organic matter and bulk density, but over time, the soils may become more like those of natural salt marshes (Ford et al. 1999, Edwards and Proffitt 2003). Aside from this study, the benefits of sediment amendment in baldcypress swamps are largely untested. While there is some debate about whether or not the soils of sediment amended salt marshes may becomes more like natural wetlands over time (Streever 2000), soil changes after sediment amendment have not been studied in coastal baldcypress forests. With respect to bulk density, sediment amended wetlands become more similar to natural wetlands over time. Immediately following sediment placement, bulk density is high, and/or the organic matter is low (Lindau and Hossner 1981, Ford et al. 1999, Craft et al. 1999, Carpenter et al. 2003, Edwards and Proffitt 2003). Organic matter increases exponentially, and bulk density decreases linearly with age so that over the period of several decades, sediment amended marshes become similar to natural marshes (Edwards and Proffitt 2003). In our study of baldcypress swamps, we observed the same initial patterns as has been observed in other coastal wetland types treated with sediment amendments. In the year following the application of sediment on Treasure Island, organic matter was low, and bulk density was high (Figures 2a and 2c, respectively).

Because of the role of vegetation in creating soil organic matter, sediment amended wetlands are likely to accumulate organic matter over time if vegetation establishes (Mendelssohn and Kuhn 2003). In the case of our study, the organic matter in the sediment increased along with a silt fraction (Figure 2d). This finer fraction of sediment including

both organic matter and silt may act as an immobilization mechanism for some ions (Chan et al. 1982, Dunbabin and Bowmer 1992), which is often related to an associated increase in surface charge (Bubb et al. 1990, Birch and Taylor 2000). In the case of the sediment amended swamps in our study, adult baldcypress trees and other vegetation already were present on the sites before the project. Black willow established after the sediment placement, leading to an increase in below-ground biomass overall (Middleton and Jiang accepted). Therefore, an increase in organic matter and associated shifts in biogeochemical processes are likely to occur in these sediment amended swamps over time.

While the relationship of sediment characteristics and biogeochemical function is clear, it is also true that sediment amendments could alter physical properties of swamp soils, with some repercussions related to stability following disturbances. Geotechnical weakness was found in the soils of low salinity fresh and intermediate marshes in Louisiana at depths that corresponded to past storm or crevasse splay deposition of sediments, with peat above and below the sediment deposition layer (Howe et al. 2010). While salt marshes with a soil bulk density of less than 0.2 g cm^{-3} cannot maintain vegetation (DeLaune et al. 1979), salt marshes generally have great deal of soil strength because of the deep rootedness of salt marsh species (Howe et al. 2010). Soil bulk densities of salt marshes reported in the literature range from 0.2 to 0.9 (Table 3). While baldcypress swamps apparently have lower bulk density (0.1 to 0.6; Table 3), these same baldcypress swamps are very resilient to storms. Perhaps due in part to the structural stability conferred by knees, the baldcypress trees at Jean Lafitte NHP&P experienced little damage, and the swamps themselves did not experience any surface erosion during Hurricane Katrina in 2005 (Middleton 2009). It is not known if any long-term soil weakness in baldcypress swamps could result from sediment layered with

peat, as has been observed in other freshwater wetlands in Louisiana (Howes et al. 2010). Another question related to the physical properties of the soils in sediment amended baldcypress swamps has to do with whether or not the weight of sediment could cause stress to the roots of trees.

Conclusions

We compared the soil characteristics of coastal baldcypress swamps treated with sediment amendments with natural swamps. The sediment in the amended forests had different soil characteristics and depth profiles than soils in the natural forests. After three years, dewatering and compaction of the dredge spoil had occurred but the dredge spoil contained low organic matter content, as well as high salinity, bulk density, and mineral content. One site had a higher elevation and drier soil than the other (Site 1 versus Site 2 on Treasure Island). Because organic matter changes the biogeochemical properties of soils with respect to ion immobilization and water holding capacity, the future characteristics of the soil are likely to depend on the ability of vegetation to add organic matter to these rehabilitated swamps. The physical properties of these soils also vary, e.g., the bulk density is much higher in sediment amended than in natural swamps. It is not known if the weight of sediment amendments could contribute to soil instability during storm activity as related to sediment layers within peat layers, or if the weight of sediment might damage the roots of trees. Generally, this study suggested that shallow rather than deep depths of sediment are more likely to yield environments beneficial to sinking baldcypress swamps in coastal Louisiana.

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Table 1. Split-plot ANOVA of a) arcsine transformed percent organic matter, and b) log transformed bulk density. The percent mineral matter is the remaining portion of the total matter, which includes percent organic matter, so the statistical tests are the same. Significance is indicated by "*", $P < 0.5$; '**', $P < 0.01$ level; '***', $P < 0.001$.

a)

Source	df	F	*P*	
Swamp Type	1	161.1	<0.0001	***
Depth	4	36.9	<0.0001	***
Swamp Type x Depth	4	41.5	<0.0001	***
Swamp Type [Site]	2	28.5	<0.0001	***

b)

Source	df	F	*P*	
Swamp Type	1	14.5	0.0031	**
Depth	4	4.7	0.0005	***
Swamp Type x Depth	4	8.8	<0.0001	***

Swamp Type [Site]	2	8.1	0.0011 **

Table 2. Soil characteristics at various depths (0 to 50 cm) in sediment amended swamps in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve including sediment type, color, salinity (ppt), pH, % organic matter, % water content, bulk density (g cm^3) and texture (% clay, sand and silt). ANOVA main effects of site (df = 1), depth (df = 4) and interactions site x depth (df = 4), respectively include: salinity (F = < 0.1, P = 0.8407, F = 1.1, P = 0.3571, F = 1.6, P = 0.1917), pH (F = 0.3, P = 0.5693, F = 0.2, P = 0.9327, F = 1.3, P = 0.2807), percent organic matter (F = 1.0, P = 0.3125, F = 3.2, P = 0.0245, and F = 6.2, P = 0.0006, respectively), percent water content (F = 6.4, P = 0.0156, F = 2.1, P = 0.0964, F = 3.1, P = 0.0250, respectively), soil bulk density (F = 2.1, P = 0.0798, F = 0.89, P = 0.4227, F = 0.4929, P = 0.6157, respectively), and soil texture (% clay: F = 3.2, P = 0.0835, F = 1.0, P = 0.3969, F = 1.2, P = 0.3338, respectively; % sand: F = 1.1, P = 0.3017, F = 2.1, P = 0.1057, F = 0.4, P = 0.7884, respectively; % silt: F = 2.0, P = 0.1642, F = 2.0, P = 0.1184, F = 0.4, P = 0.7769, respectively). Different letters indicate that the mean comparison of the variable differs from one another based on contrasts in ANOVA (p < 0.0001).

depth (cm)	sediment type†	soil color	soil salinity (ppt)	soil pH	soil organic matter %	soil water content %	soil bulk density g cm^3	soil texture % clay	sand	silt
Site 1										
0-10	D	10YR 6/1	0.15^{a}	5.68^{a}	9.99^{a}	2.9^{b}	0.60^{a}	3.2^{a}	54.8^{a}	42.0^{a}
10-20	D	10YR 6/2	0.10^{a}	6.46^{a}	7.07^{ab}	3.4^{ab}	0.80^{a}	2.1^{a}	57.8^{a}	40.1^{a}
20-30	T	10YR 8/3	0.25^{a}	5.72^{a}	10.68^{ab}	5.2^{ab}	0.86^{a}	1.9^{a}	53.1^{a}	45.0^{a}
30-40	O	10YR 2/1	0.45^{a}	4.74^{a}	30.76^{ab}	7.1^{ab}	0.44^{a}	2.1^{a}	42.5^{a}	55.3^{a}
40-50	O	2.5Y3/1	1.00^{a}	4.58^{a}	53.58^{ab}	5.5^{ab}	0.41^{a}	3.3^{a}	39.4^{a}	57.4^{a}
Site 2										
0-10	D	10YR 3/1	0.40^{a}	4.95^{a}	33.77^{ab}	5.5^{ab}	0.33^{a}	2.1^{a}	46.1^{a}	51.8^{a}
10-20	T	10YR 3/1	0.30^{a}	4.45^{a}	46.08^{b}	8.4^{a}	0.23^{a}	5.1^{a}	42.3^{a}	52.6^{a}
20-30	O	10YR 3/3	0.20^{a}	4.63^{a}	60.49^{ab}	8.0^{ab}	0.26^{a}	3.3^{a}	42.9^{a}	53.9^{a}
30-40	O	5PB4/1	0.65^{a}	5.14^{a}	30.67^{ab}	5.9^{ab}	0.41^{a}	2.0^{a}	44.7^{a}	53.4^{a}
40-50	O	10YR6/2	0.55^{a}	5.45^{a}	19.93^{ab}	4.2^{ab}	0.52^{a}	3.1^{a}	37.4^{a}	59.4^{a}

† D represents the sediment amendment in the soil horizon, T represents transitional belt from sediment to original soil, O represents original soil covered by sediment amendment.

Table 3. Comparisons of surface soil characteristics (less than 15 cm depth) of associated wetland types. “N/A” is not available.

Site	Vegetation Type	% organic matter	% clay	% sand	pH	soil salinity (ppt)	bulk density (g cm^{-3})	source
sediment amended, Site 1, LA	baldcypress	9.9	3.2	54.8	5.7	0.2	0.6	this study
sediment amended, Site 2, LA	baldcypress	33.9	2.1	46.1	6.0	0.4	0.3	this study
natural forest, Site 1, LA	baldcypress	60.3	n/a	n/a	n/a	n/a	0.1	this study
natural forest, Site 1, LA	baldcypress	43.8	n/a	n/a	n/a	n/a	0.1	this study
Reserve Middle, SC	baldcypress	n/a	n/a	n/a	n/a	0.8[2]	0.5	Krauss et al. 2009
Reserve Lower, SC	baldcypress[1]	n/a	n/a	n/a	n/a	1.3[2]	0.1	Krauss et al. 2009
Waccamaw Upper, SC	baldcypress	n/a	n/a	n/a	n/a	0.1[2]	0.2	Krauss et al. 2009
Waccamaw Middle, SC	baldcypress	n/a	n/a	n/a	n/a	0.7[2]	0.3	Krauss et al. 2009
Waccamaw Lower, SC	baldcypress	n/a	n/a	n/a	n/a	2.1[2]	0.2	Krauss et al. 2009
Savannah Upper, GA	baldcypress	n/a	n/a	n/a	n/a	0.1[2]	0.4	Krauss et al. 2009
Savannah Middle, GA	baldcypress	n/a	n/a	n/a	n/a	0.8[2]	0.2	Krauss et al. 2009
Savannah Lower, GA	baldcypress	n/a	n/a	n/a	n/a	3.4[2]	0.4	Krauss et al. 2009
Savannah Lower, GA	baldcypress	n/a	n/a	n/a	n/a	3.4[2]	0.4	Krauss et al. 2009
Bayou Teche, LA	baldcypress[1]	n/a	n/a	n/a	n/a	0.4[2]	0.4	Krauss et al. 2009
Mandalay, LA	baldcypress	n/a	n/a	n/a	n/a	1.6[2]	0.4	Krauss et al. 2009

Treasure Island, LA	baldcypress	n/a	n/a	n/a	n/a	2.0[2]	0.1	Krauss et al. 2009
Fleming, LA	baldcypress	n/a	n/a	n/a	n/a	2.1[2]	0.2	Krauss et al. 2009
Donnelley Wildlife Management, SC	swamp tupelo (*Nyssa sylvatica*) transition[1]	3.6	37.6	35.5	5.0	n/a	n/a	Burke et al. 1999
Donnelley Wildlife Management, SC	swamp tupelo flooded[1]	5.5	49.5	31.0	4.8	n/a	n/a	Burke et al. 1999
southeastern, LA	brackish marsh, sediment amended, saltmeadow cordgrass (*Spartina patens*)	n/a	n/a	n/a	n/a	n/a	0.5	La Peyre et al. 2009
southeastern, LA	brackish marsh, natural, saltmeadow cordgrass	n/a	n/a	n/a	n/a	n/a	0.2	La Peyre et al. 2009
Lake Barre, LA	salt marsh, salt marsh cordgrass (*Spartina alterniflora*)	31.5	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
W Madison Bay, LA	brackish marsh, salt marsh cordgrass	44.5	n/a	n/a	n/a	n/a	0.1	Nyman et al. 1993
Charles Theriot, LA	salt marsh, salt marsh cordgrass	17.4	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
Bay la Peur, LA	salt marsh, salt marsh cordgrass	24.4	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
downstream Chitique, LA	salt marsh, salt marsh cordgrass	21.2	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
midstream Chitique, LA	salt marsh, salt marsh cordgrass	21.9	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
upstream Chitique, LA	salt marsh, salt marsh cordgrass	29.9	n/a	n/a	n/a	n/a	0.2	Nyman et al. 1993
Grand Bayou, LA	salt marsh, salt marsh cordgrass	31.0	n/a	n/a	n/a	n/a	0.2	Nyman et al. 1993
downstream deMangue, LA	salt marsh, salt marsh cordgrass	39.5	n/a	n/a	n/a	n/a	0.2	Nyman et al. 1993
midstream deMangue, LA	salt marsh, salt marsh cordgrass	23.5	n/a	n/a	n/a	n/a	0.3	Nyman et al. 1993
upstream deMangue, LA	salt marsh, salt marsh cordgrass	29.6	n/a	n/a	n/a	n/a	0.2	Nyman et al. 1993

DuFrene, LA	salt marsh, salt marsh cordgrass	31.3	n/a	n/a	n/a	n/a	0.2	Nyman et al. 1993
Venice, LA	salt marsh, natural (no deposition[3])	n/a	n/a	7.0	n/a	13[4]	0.3	Slocum&Mendelssohn 2008
Venice, LA	salt marsh, natural (moderate deposition[3])	n/a	n/a	22.0	n/a	19[4]	0.5	Slocum&Mendelssohn 2008
Venice, LA	salt marsh, natural (high deposition[3])	n/a	n/a	58.0	n/a	18[4]	0.9	Slocum&Mendelssohn 2008

[1] This site was historically tidal or likely was historically tidal.

[2] Salinity was measured from a groundwater well.

[3] Sediment accidently overflowed into an adjacent saltmarsh with treatments designated as no, moderate and high deposition (0 to 22 cm depth).

[4] Salinity of the soil interstitial water was measured.

Figure Captions

Figure 1. Coastal study sites in baldcypress swamps south of New Orleans in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve (lower left) including two natural (black circles) and two sediment amended swamps (lower right; white triangles).

Figure 2. Soil characteristics of natural and sediment amended swamp forests in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve including the interaction of swamp type and depth from ANOVA for a) percent organic matter (natural: $r^2 = 0.556$, $p < 0.0001$, arcsine % organic matter = 0.557 - 0.111 * depth; sediment amended: $r^2 < 0.01$, P = 0.837, arcsine % organic matter = 0.040 + 0.0005 * depth, b) mineral content (natural: $r^2 = 0.601$, $p < 0.0001$, arcsine % mineral = 0.452 + 0.173 * depth; sediment amended: $r^2 < 0.01$, P = 0.6953, arcsine % mineral = 1.304 - 0.0037 * depth), and, c) bulk density (natural: $r^2 = 0.491$, P = 0.0036, log bulk density = 0.002+ 0.064 * depth; sediment amended: $r^2 < 0.1$, P = 0.6214, log bulk density = 0.123 - 0.004 * depth. For sediment amended swamp forests only, the d) percent organic matter versus silt content of the soil is given ($r^2 = 0.37$, $p < 0.0001$; % organic matter= -5.0 + 0.16 * % silt). The illustrated regressions are based on untransformed data.

Figure 3. Elevations of coastal baldcypress swamp forests in the Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve. Measurements were taken at two SETs in each of two sites in each swamp type including natural swamp forests (ECC:

SET13-14; ECP: SET 15-16) and sediment amended swamp forests (Site 1: SET 99-100; Site 2: SET 101-102). The measurements began just before the addition of the sediment in the amended swamps in December 2006. The SET approach measures sediment height relative to a fixed SET monument. Actual elevations were estimated by measuring elevations at each SET monument in January 2010 with a Trimble R8 GNSS dual frequency receiver. Elevation estimates were corrected using elevation control points collected using the LSU Gulfnet Real-time Network (Uncertainty = 1- 5 cm; Center for Geoinformatics 2006). The coastal region is subsiding at a rate of 4-5 ± 2 mm yr^{-1} (Shinkle and Dokka 2004).

Figure 4. Photograph of soil layering with different colors representing differences in texture class in a sediment amended swamp, collected on Treasure Island, Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve in December 2008. Sand layers were white; silt and clay layers were black.

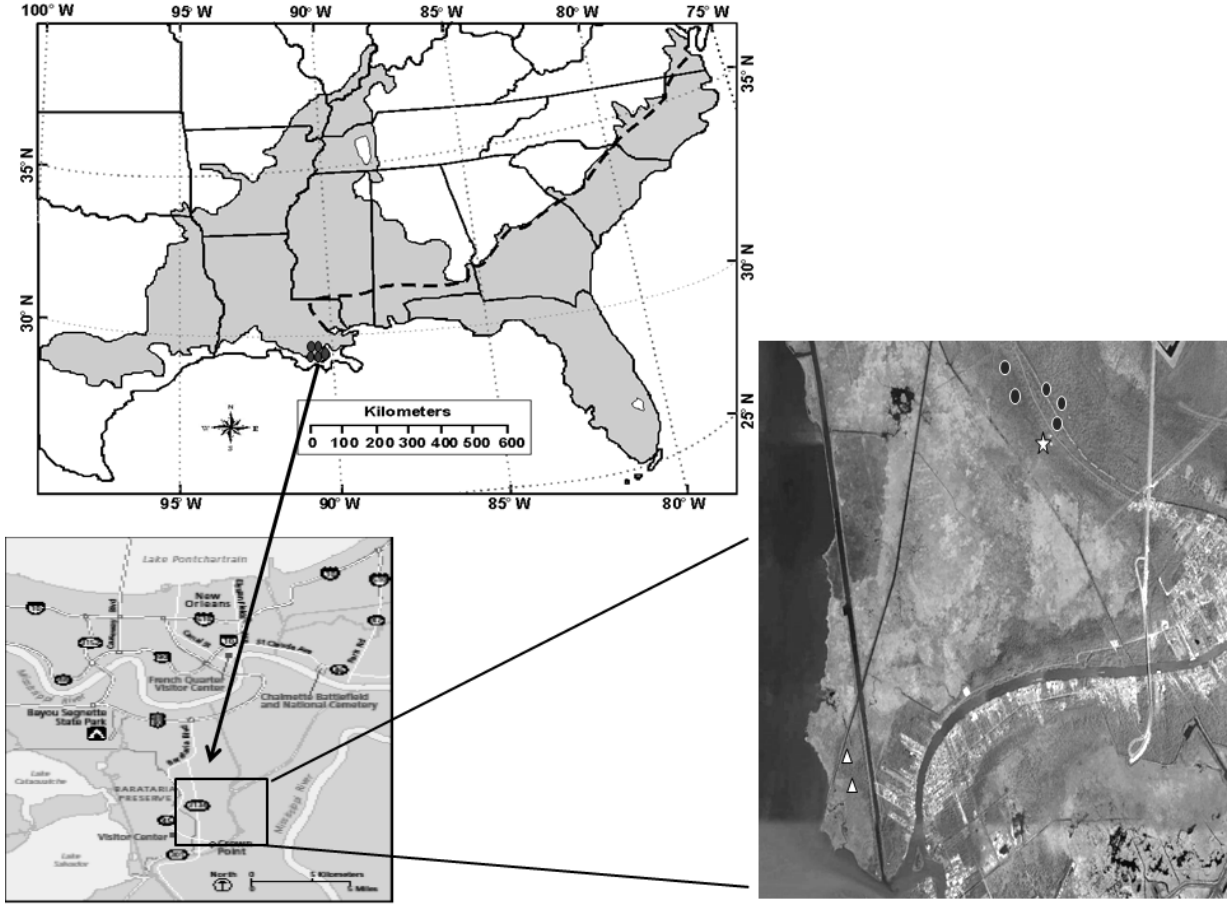
100° W
95° W
90° W
85° W
80° W
75° W
35° N
30° N
25° N
Kilometers
0 100 200 300 400 500 600
Lake Pontchartrain
New Orleans
French Quarter Visitor Center
Chalmette Battlefield and National Cemetery
Bayou Sauvage State Park
Visitor Center
Point
North

Figure 1.

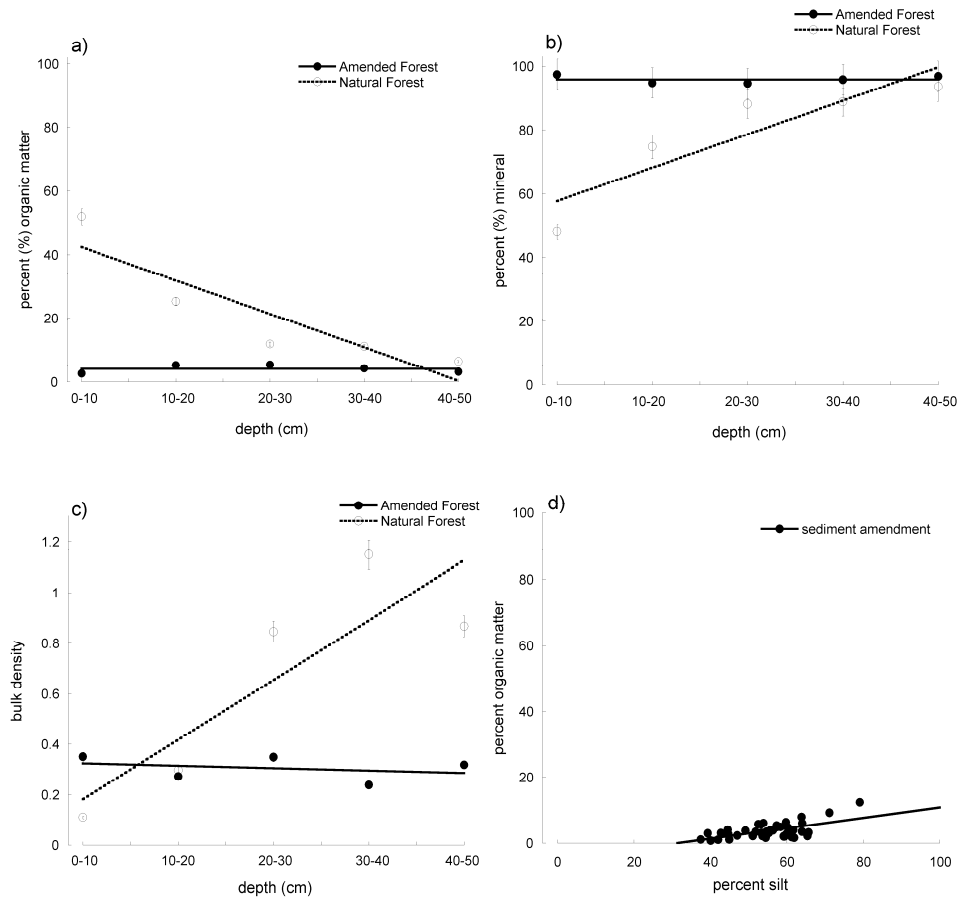
a)
Amended Forest
Natural Forest
percent (%) organic matter
depth (cm)
0-10
10-20
20-30
30-40
40-50
b)
Amended Forest
Natural Forest
percent (%) mineral
depth (cm)
c)
Amended Forest
Natural Forest
bulk density
depth (cm)
d)
sediment amendment
percent organic matter
percent silt

Figure 2.

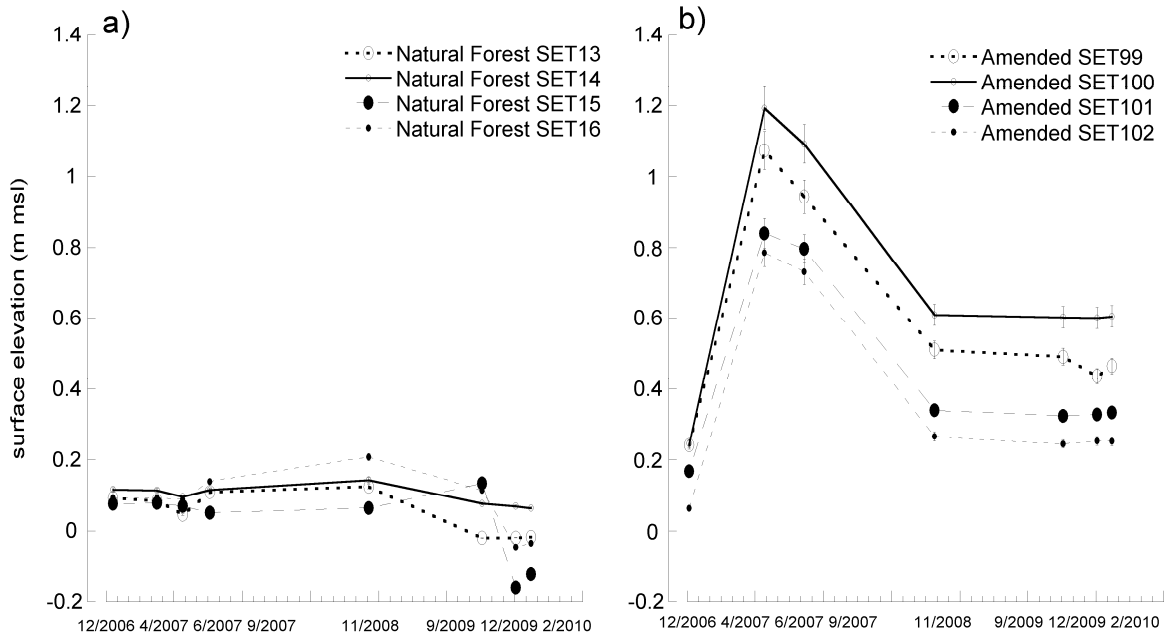
a)
Natural Forest SET13
Natural Forest SET14
Natural Forest SET15
Natural Forest SET16
surface elevation (m msl)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
12/2006 4/2007 6/2007 9/2007 11/2008 9/2009 12/2009 2/2010
b)
Amended SET99
Amended SET100
Amended SET101
Amended SET102
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
12/2006 4/2007 6/2007 9/2007 11/2008 9/2009 12/2009 2/2010

Figure 3.

DredgeSoilDec6-2010

Figure 4.