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Vertical Movement and Substrate Characteristics of Oligohaline Marshes Near a High-Sediment, Riverine System

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ABSTRACT

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In coastal Louisiana, large sediment diversions from the Mississippi and Atchafalaya Rivers have been planned to enhance marsh accretion and productivity and reverse an overall deterioration of coastal marshes. Located between these rivers, there are extensive buoyant marshes in the freshwater and oligohaline zones (about 70% of the vegetated area), and little information exists on how buoyant substrates respond to mineral sediment introduction. The purpose of this study was to understand the vertical movement (buoyancy) and substrate properties of oligohaline marshes with increasing distance from the Atchafalaya River-Fourleague Bay system, a significant mineral sediment source. To do this thirty-seven stations were established (within a study area of 125 km^2) where vertical marsh movement and marsh hydrology were monitored for a year, and soil cores were collected and analyzed for bulk properties. With increasing distance inland from the sediment source, there were significant increases in vertical movement of the marsh mat and decreasing mineral sediment content in the soil profile. In the interior marshes farthest from the sediment source, the average mat movement was greater than 15 cm, and some sites exceeded 25 cm. Non-buoyant marshes with high substrate bulk density were located closest to the sediment source. Mineral sediment deposition appeared to be a discontinuous process controlled by large events such as hurricanes and tropical storms, rather than average yearly flood events. A comparison of our data (from oligohaline marshes) with other studies (from freshwater marshes) suggests that increases of mineral matter within the upper peat matrix may decrease the vertical movement of marsh substrates.

ADDITIONAL INDEX WORDS: *Coastal Louisiana, oligohaline marshes, hydrology, substrate properties, floating marshes.*

INTRODUCTION

The massive coastal wetland loss in Louisiana over the past several decades has created a heightened concern to wisely manage these marshes. Louisiana has 41% of our nation's coastal wetlands, and it also has the highest rate of loss, which has exceeded 1,700 ha/yr (BAUMANN and TURNER, 1990). Various factors have been hypothesized as leading causes of wetland loss: hydrologic modification (TURNER, 1997); decreased sediment delivery to marshes due to Mississippi River channelization (GAGLIANO *et al.,* 1981); natural substrate subsidence and sea-level rise (BOESCH *et al.,* 1994; PENLAND *et al.,* 1988); and other factors such as erosion, oil and gas removal, herbivory, and saltwater intrusion. Marsh loss in Louisiana is well documented (TURNER and CAHOON, 1988; EVERS, *et al.,* 1992; BRITSCH and DUNBAR, 1993; BOESCH *et al.,* 1994), and it is probably related to a combination of several of the aforementioned factors, depending on the location within this large and diverse coastal landscape.

Floating marshes are a common landscape type within the freshwater and oligohaline zone of Louisiana occupying at least 144,000 ha within Barataria and Terrebonne Basins (SASSER *et al.,* 1996; EVERS *et al.,* 1996). Historically, these expansive, buoyant coastal marshes in Louisiana were referred to as "flotant" (freshwater) and "prairie tremblant" (brackish) (RUSSELL, 1942; O'NEIL, 1949). The terms "buoyant" and "floating" are used, hereafter, to describe vertical movement of the marsh mat. Presently, buoyant marshes make up about 70% of the total vegetated area of the freshwater and oligohaline zones (or 44% of the total area including open-water, spoil banks, and developed areas) (EVERS *et al.,* 1996). Freshwater and oligohaline marsh zones comprise 12% of Louisiana's 3 million acres of coastal wetlands. In this deltaic wetland environment that experiences up to 1.5 cm yr^{-1} in subsidence and a 0.23 cm yr^{-1} sea-level rise (TURNER, 1991), buoyant marsh mats may provide a distinct survival mechanism.

The Louisiana Coastal Wetlands Restoration Plan (1993), developed to address the objectives of the Coastal Wetlands Planning, Protection and Restoration Act (Public Law 101–646), outlined restoration strategies to ameliorate Louisiana's deteriorating coastal wetlands. One priority of this plan has been to divert high-sediment water from the Mississippi and

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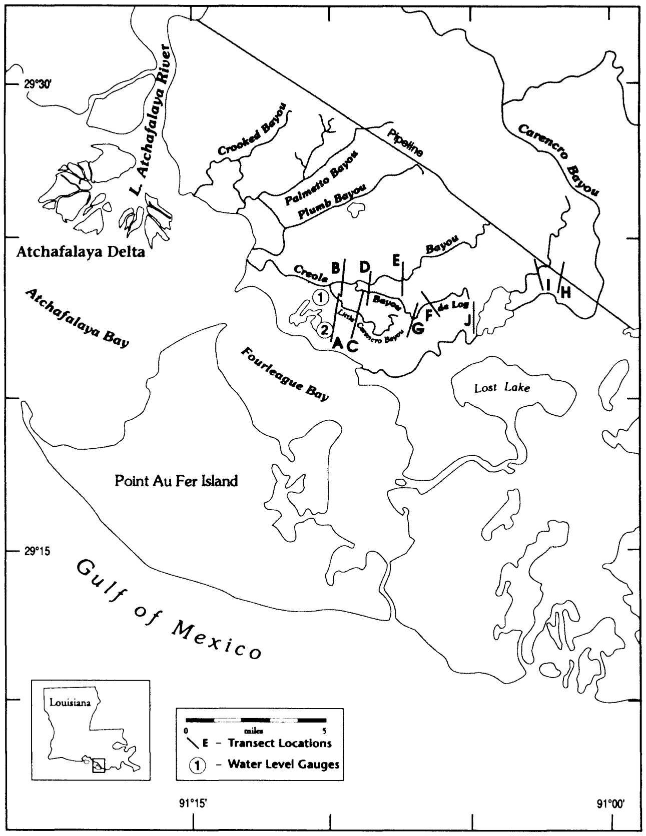

Figure 1. The location of the study area relative to the mouth of the Atchafalaya River and Fourleague Bay, Louisiana. Transects (labeled A–J) included interior and edge marsh sites where vertical marsh movement and substrate characteristics were measured. Circles correspond to the water level gauges that measured open water bayou (1) and interior marsh (2) water levels along Little Carencro Bayou.

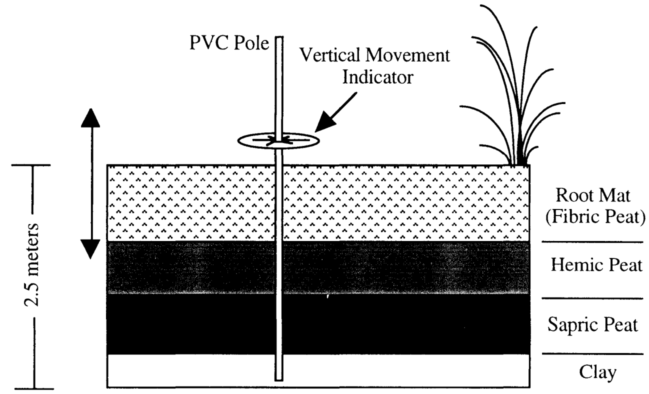

Figure 2. Diagram of a vertical movement indicator used to measure the maximum upward movement of the marsh surface. A buoyant marsh mat moves the disk upward, thereafter the disk holds its position until an event of greater movement. The PVC pole is driven through the peat to a firm substrate. Increasing stages of peat decomposition with depth below the root mat were evident in the oligohaline marsh substrates of this study.

Atchafalaya Rivers to enhance marsh accretion, plant productivity, and freshwater retention (Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1997). The response of buoyant marshes to mineral sediment introduction is not well understood. The objective of this study was to describe the vertical movement and substrate characteristics of oligohaline marshes with increasing distance from a major sediment source, the mouth of the Atchafalaya River and the entrance to Fourleague Bay.

METHODS

Study Area

The study site includes an area 10 km east of the mouth of the Atchafalaya River and extending 4 km from the north shore of Fourleague Bay (Figure 1). With an average annual flood discharge of 7,500 cms, an annual average of 67 million metric tons of sediment are supplied to Atchafalaya Bay by the River (Roberts *et al.*, 1980; Roberts *et al.*, 1997). Other studies in the Atchafalaya-Fourleague Bay complex have documented the physical influences (freshwater and sediments) of the Atchafalaya River (Denes and Caffrey, 1988; Wiseman and Inoue, 1993). The major drainages within the watershed of our study include Bayou de Log and Little Carencro Bayou, which drain into the major conduit of Creole Bayou (Figure 1). These waterways are influenced by microtides (30–40 cm) with semi-diurnal and diurnal frequencies. The watershed was considered "natural" because of the relative lack of channelization and dredging associated with oil and gas operations; however, a small portion of the study area is influenced by a pipeline canal to the northeast of Carencro Lake (Figure 1). Hurricane Andrew made landfall on August 26, 1992, in this general vicinity and upheaved many areas of interior marsh substrate (Cahoon *et al.*, 1995; Guntenspergen *et al.*, 1995).

Our study area was mapped as an oligohaline zone (0.5-5 psu) based on the vegetation communities (Chabreck and Linscombe, 1978); this agreed with our observations. The communities are usually dominated by *Spartina patens*, *Sagittaria lancifolia*, or *Scirpus americanus*. The soil types have been described as ranging from "deep peats" in the interior marshes to the "mucky clays" which border the northern edge of Fourleague Bay (Soil Survey of Terrebonne Parish, Louisiana, 1949).

The land change rates for the study area varied from a loss of 77 ha/yr from 1955–1972 and a gain of 25 ha/yr from 1972–1978 (Baumann and Adams, 1982). The marshes within the Creole Bayou drainage appear robust and healthy, especially compared to some marshes to the north and east of this area which are apparently deteriorating.

Measurements of Vertical Marsh Movement

To measure the vertical movement of the marsh substrate (buoyancy), we developed a vertical movement indicator from 1/2 inch schedule 40 PVC pipe and toothed metal disks (Figure 2). The PVC pipe was driven through approximately 3.0

m of peat into a firm mineral substrate, and the metal disk was moved to the marsh surface. Upward movement of the marsh mat caused the disk to hold an elevated position until an event of greater mat movement. Therefore, our measurements showed a maximum vertical movement over a given time period.

Ten transects for the vertical movement indicators were selected within zones (west, central, east) of increasing distance inland from the major sediment source of the study area—the Atchafalaya River-Fourleague Bay system (Figure 1). Each transect comprised two interior sites and two natural levee edge (edge) sites situated perpendicular to one of the three major drainages (Creole Bayou, Little Carencro Bayou, and Bayou de Log); an exception was transect J in the east zone, which contained only one interior site and no edge site. Each site contained two replicate vertical movement indicators which were placed approximately 10–20 m apart.

The western zone included transects A, B, C, and D, which contained 8 interior and 8 edge sites. The central zone included transects E, F, and G, which contained 6 interior and 6 edge sites. The eastern zone included transects H, I, and J, which contained 5 interior and 4 edge sites. Thus, there were a total of 19 interior and 18 edge marsh sites for the study.

Vertical movement indicators were serviced five times between April 1994 and April 1995. To determine the amount of vertical mat movement, the distances from the top of the pole to the metal disk and to the marsh surface were measured and subtracted. These measurements indicated how much the marsh moved between service dates and the present elevation of the marsh mat relative to previous service dates. We standardized all measurements to the initial deployment marsh elevation.

Substrate Sampling

Two replicate marsh cores (7.62 cm diameter aluminum pipe) were taken to a depth of 40–60 cm at each site except for one edge site on transect C and all the sites associated with transect D. This resulted in a total of 64 cores. Compaction of the cored substrate during field sampling was minimized to 1-cm or less by measuring the cored substrate surface relative to the ambient marsh substrate surface. Cores that exceeded 1-cm of compaction were discarded. One core was used for depth specific analysis of bulk density and organic content. The other core was used to verify the presence of clay lenses, horizon changes, and the state of decomposition of organic matter (fibric, hemic, or sapric). The cores for bulk density were frozen after field collection and analyzed for bulk density and organic matter for each 1-cm interval. The use of a band-saw enabled the controlled sectioning of these 1-cm intervals of the frozen core. Every fifth section was measured for thickness in three positions using digital calipers to adjust for any change in volume (sample thickness) caused by machine or operator variability. The average thicknesses were used to estimate the true volume. Organic matter was determined by loss-on-ignition at 550°C for 1-hour (SASSER *et al.*, 1996), and the entire section was ignited with no subsampling involved. Bulk density was expressed as the dry weight of each section per unit volume (g cm^{-3}).

Data Analysis of Vertical Marsh Movement and Substrate Properties

The data analysis was designed to test for changes in mat movement and soil characteristics along two gradients: (1) from the mouth of the Atchafalaya River system increasing inland; and (2) from a natural levee edge marsh of a bayou to the interior marsh. To determine the gradient from the river system to inland marshes, transects were classed into a ZONE variable (West, Central, East) relative to their distance from the river system. The positions of interior marsh or natural levee edge marsh were classed by a TYPE variable (interior and edge). The variability associated with TYPE, ZONE, and TYPE*ZONE were the main effects in the Analysis of Variance (ANOVA) models.

A total range of vertical movement for each site (one average of the two replicate indicators) was determined for the one year study period. This range of mat movement for each site over the whole study period was the dependent variable in the ANOVA. Independent variables included TYPE and ZONE. The residuals were verified for normality with a Shapiro-Wilk normal probability test before being analyzed with an ANOVA (SOKAL and ROHLF, 981). A two-way ANOVA with Tukey's Honest Significant Difference (HSD) was used to test differences in mat movement among TYPE and ZONE treatments. A separate ANOVA was used for analyzing the substrate data. Soil organic matter and bulk density were averaged over the upper 30 cm and used as independent estimates of error ($n = 32$). We used the average of the upper 30 cm, because it was the horizon of most active root production (also gas accumulation) and susceptible to buoyant detachment. Unequal sample sizes for ZONE and TYPE were present in the design. For each pairwise comparison of interest between ZONE and TYPE, Least Significant Difference (LSD) tests with Bonferroni adjustments (alpha = 0.05/number of pairwise comparisons) were used to control for the overall experiment-wise error (FREUND and WILSON, 1993).

Hydrology

Water levels were monitored at open water stations on Little Carencro Bayou (gauge no. 1; Figure 1), Creole Bayou (at transect E), Bayou de Log (at transect F). We also measured interior-marsh water levels near Little Carencro Bayou (gauge no. 2; Figure 1). All water level stations collected data from the spring of 1994 through the spring of 1995. A Stevens® Type A/F digital water level recorder, containing a float and counterweight mechanism, was deployed at the open water station on Little Carencro Bayou. Water levels at the remaining three stations were monitored with Fisher and Porter® 1150 series punch-tape recorders, which also contained float and counterweight mechanisms. Each gauge sampled on hourly intervals.

To determine the dominant periods of water level fluctuations at all stations across the study area, a spectral analysis was performed on the hourly data using Statistical Analysis Software (SAS/ETS, 1984). The averages of daily water level

Table 1. *The number and percentage of sites within a range of vertical mat movement. There were 8 sites (21%) with movement greater than 15 cm.*

Range of Vertical Mat Movement (cm)	Number of Sites	Percentage of Sites
0–5	16	43
5–10	8	22
>10	13	35

from both stations were correlated with a Pearson's Correlation analysis (SAS, 1989). Daily water level averages also were used to examine the occurrence of events with periods exceeding that of normal tidal fluctuations.

RESULTS

Vertical Marsh Mat Movement

Of the 37 sites measured for vertical movement, 57% moved more than 5 cm, while 43% had negligible mat movement (<5 cm) (Table 1). The average mat movement among all sites was 10.4 cm (n = 37, SE = 6.3). We found that at least 36% of the variability in mat movement could be statistically described by the distance from the river system (ZONE) and the type of marsh (interior/edge or TYPE) (Table 2). Figure 3 summarizes the average vertical marsh movement and soil bulk properties by zone and marsh habitat type (interior and edge); different letters above the means indicate significant differences based on Bonferroni tests with an overall alpha of 0.05.

Over the whole study area, vertical mat movement between edge (8.1 ± 2.6 cm, n = 18) and interior (12.6 ± 2.5 cm, n = 19) marshes was significantly different (Pr > F = 0.047; 1, 31 df). The greatest mat movement occurred in the eastern marshes (13.7 ± 3.0 cm) which was significantly greater than the western marshes (6.0 ± 2.2 cm) (Figure 3A). Mat movement in western edge marshes (4.3 ± 2.2 cm) was not significantly different from 0 cm of mat movement (Pr > T = 0.062; 31 df). Mat movement in the interior and edge marshes in the east were very similar, but the difference between interior and edge movement in the central marshes was significant (Pr > T = 0.018; 31 df) (Figure 3A).

Substrate Properties

The variables TYPE and ZONE statistically explained 45% of organic matter and 48% of the variability in bulk density (Table 2). The variation in bulk density was greatly determined by ZONE (F = 11.08; 1, 26 df, p = 0.0003), but the TYPE variable was nonsignificant (F = 2.42; 1, 26 df, p = 0.1322) (Table 2).

There was a significant difference in organic matter content in the upper 30 cm between interior (65.7 ± 4.9%) and edge (55.8 ± 5.2%) marshes. However, the bulk density between interior (0.10 ± 0.02 g cm $^{-3}$; n = 17) and edge (0.13 ± 0.02 g cm $^{-3}$; n = 15) marshes was not considered statistically different. Organic matter was 20% higher in the eastern marshes (71.5%) compared to the western marshes (51%). The bulk density values were similar between eastern (0.07 g cm $^{-3}$)and central (0.11 g cm $^{-3}$) marshes, but significantly different from western marshes (0.17 g cm $^{-3}$). The organic matter content was consistently higher among interior marshes and increased with distance from the river (Figure 3C); and inversely, soil bulk density was consistently higher among natural-levee edge marshes and decreased with distance from the river (Figure 3B).

Table 2. *ANOVA models of vertical mat movement and soil properties by ZONE (west, central, east) and TYPE (interior, edge). F-tests were based on the Type III SS. Single and double asterisks indicate significance at 0.05 and 0.01 levels, respectively.*

Source of Error	Mat Movement (n = 37) F Value (Pr > F)	Bulk Density (n = 32) F Value (Pr > F)	Organic Matter (n = 32) F Value (Pr > F)
TYPE	4.28 (0.047)*	2.42 (0.132)	4.97 (0.035)*
ZONE	4.84 (0.015)*	11.13 (0.0003)**	7.84 (0.002)**
TYPE×ZONE	1.23 (0.305)	0.06 (0.943)	0.63 (0.539)
Model R^2	0.36	0.48	0.45

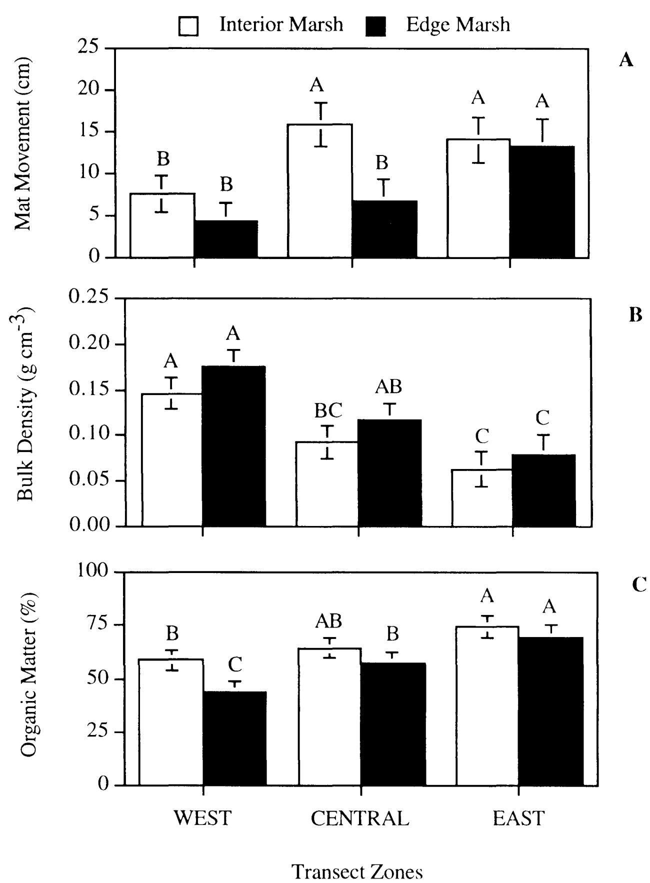

Figure 3. Average vertical mat movement (A), bulk density (B), and organic matter (C) with respect to ZONE and TYPE (LSMEAN ± 1 S.E.). The average mat movement is based on the data from the whole study period. Letters represent significant differences between the means based on Bonferroni pairwise comparisons. The natural levee edge marsh is shaded and the interior marsh is white.

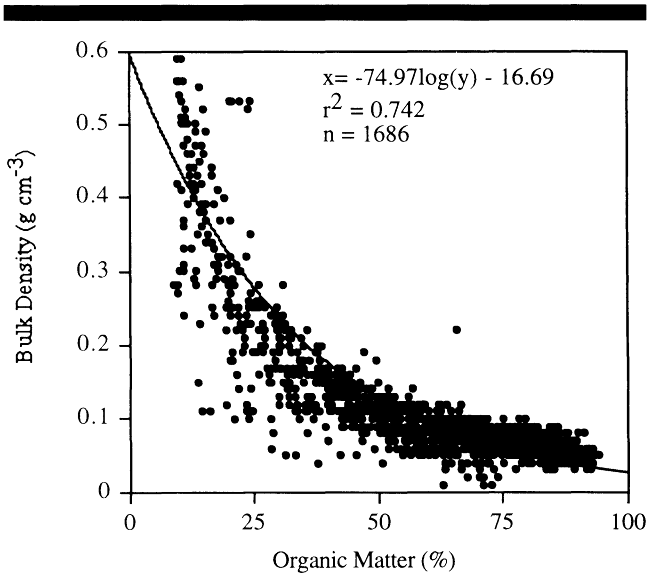

Figure 4. The relationship between soil bulk density and organic matter content for the 1686 1-cm depth intervals. Most of the soil samples were high in organic matter.

The relationship between soil bulk density and organic matter for each of the 1-cm increments is shown in Figure 4. The relationship between these two parameters maintained a similar curvilinear relationship as described by GOSSELINK *et al.*, (1984) for flooded Louisiana soils (Figure 4). We found that greater than 55% of the 1686 1-cm increments were greater than 65% organic.

Each soil profile (32 cores) was examined by plotting bulk density by depth for every 1-cm increment. Bulk density rather than organic matter content was used, because bulk density is controlled by mineral deposition and not by organic matter content (GOSSELINK *et al.*, 1984). Figure 5 includes profiles that were representative of the general changes in bulk density (by ZONE and TYPE) with increasing depth. Bulk density values less than 0.1 g cm^{-3} correspond to organic contents of at least 60%.

Hydrology

Plots of daily average water levels showed that water level variability was greater in the open-water bayou station (Figure 6A) compared to the interior marsh station (Figure 6B). Water levels in the open water bayou (gauge no. 1) exhibited a noticeable seasonal pattern; however, this seasonal response was much less pronounced in the interior marsh (gauge no. 2). Over the one year time period, water levels ranged from a total of 60 cm in the interior marsh station and 125 cm in the open-water bayou station. The daily range of water levels were 48.2 ± 13.1 cm for the open-water bayou station and 4.03 ± 5.2 cm for the interior marsh site.

Spectral analysis of hourly water level data indicated prominent peaks in the spectral density at the diurnal (23.93 hr) and semi-diurnal (12.42 hr) tidal periods (POND and PICKARD, 1983) in the open water stations but not in the interior

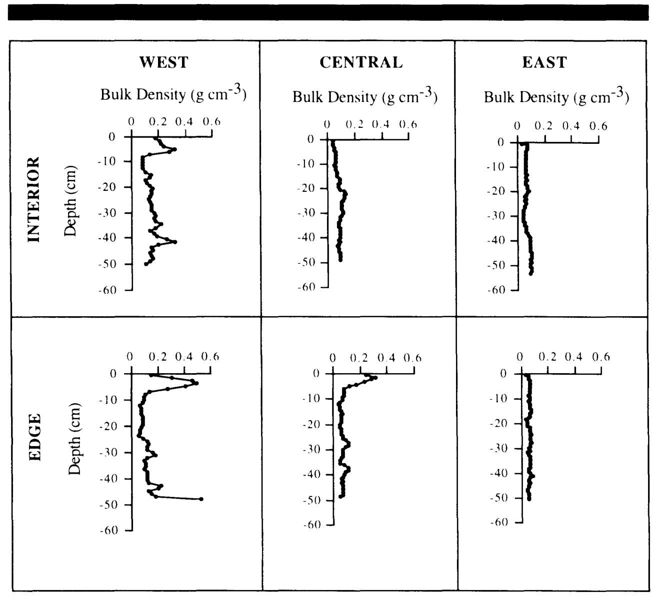

Figure 5. Soil bulk density profiles representative of the study area. The noticeable sediment "spikes" in the upper 10 cm correspond to the deposition associated with Hurricane Andrew. Bulk densities less than 0.1 g cm^{-3} are largely organic in composition.

marsh. There was a high coherence (>0.90) in water level fluctuations at periods greater than the diurnal tidal signals among all of the open water gauges (indicating a high connectivity of water movement within the watershed). Since

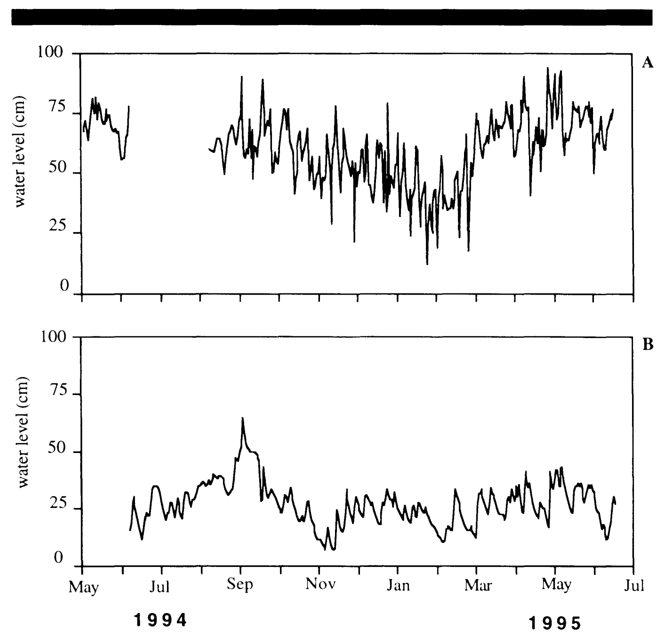

Figure 6. Daily average water levels from the open water bayou station at Little Carencro Bayou (A) and the interior marsh station (B) (month ticks on the x-axis correspond to the 5th day of the month shown). Based on a linear regression, the relationship between the open water bayou and interior marsh stations was poor (r^2 = 0.19).

most of the water level changes occurred at time periods exceeding that of normal tidal fluctuation (approximately three days), we used daily water level averages in the regression analyses. A linear regression of daily water level averages between the open-water bayou (gauge no. 1) and interior marsh (gauge no. 2) stations showed a poor correlation (r^2 = 0.194).

There was a gradual increase of water level in the interior marsh begining in August 1994, and it continued through mid-September (Figure 6B). During this time period, a weak tropical disturbance in the northern Gulf of Mexico produced peak marsh water levels (over the complete study period) on September 16, 1994 (Figure 6B). In the spring of 1995, water levels peaked with an intense period of rainfall that occurred from May 8–10. This period of high rainfall produced a "three-pronged" water level signal, which was obvious in both the open water and interior marsh stations (Figures 6 A, B). Although peak bayou (open water) water levels were similar between the large September 1994 and May 1995 events; marsh water levels were considerably lower during the May 1995 event.

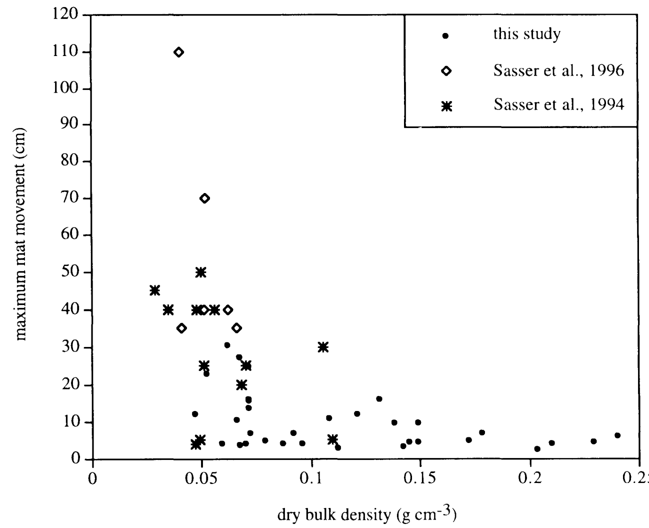

Figure 7. Marsh mat movement (cm) related to the average bulk density of the upper 30 cm of the marsh substrate. Data from this study is from oligohaline marshes, and the data from Sasser et al. (1994; 1996) were mostly from coastal freshwater marshes, which exhibit greater mat movement and lower bulk density.

DISCUSSION

A gradient of increasing vertical marsh movement and decreasing mineral sediment influence with distance from the Atchafalaya River-Fourleague Bay system suggests that the presence of an adjacent sediment source may limit the potential buoyancy of marsh substrates. The eastern-most sites, which were located in the upper reaches of the Creole Bayou watershed and exhibited considerable vertical movement at both edge and interior sites, seem to be removed from the sediment influence of the Atchafalaya system as evidenced by low bulk density and high organic matter. In general, interior marshes exhibited greater vertical mat movement compared to the natural levee edge marshes. A trend of higher bulk density in the edge marshes compared to the interior marshes may account for the observed differences in mat movement. In general, the process of higher sedimentation occurring in natural levee edge marshes compared to interior marshes, as observed by BAUMANN *et al.* (1984), may be more prevalent in the marshes bordering the drainages close to the Atchafalaya River-Fourleague Bay system.

A comparison of the data from this study in oligohaline marshes with previous studies in freshwater marshes (SASSER *et al.*, 1996; SASSER *et al.*, 1994) suggests that vertical movement of marsh mats are limited by high mineral contents (high bulk density) in the upper soil horizon (Figure 7). Moreover, highly buoyant substrates are almost purely organic with very low bulk densities (<0.07 g cm^{-3}) (Figure 7). Low bulk density substrates, however, do not always exhibit buoyancy. For example, several sites in our study, containing low bulk densities (<0.1 g cm^{-3}), did not exhibit significant mat movement (Figure 7). In these cases, the anchorage of live roots to a firm underlying substrate (clay) may inhibit vertical mat movement. Another plausible explanation may be related to root mat or substrate integrity (*i.e.* insufficient gas production within the peat or a lack of root mat cohesion), which may be influenced by the vegetation composition and health (KING *et al.*, 1984; HOGG and WEIN, 1988; BURDICK, 1989). Interestingly, we found that non-buoyant marshes still exhibited several centimeters of dilation or expansion, which may be similar to such a phenomenon described by others (INGRAM, 1983; AHTI, 1987; NUTTLE and HEMMOND, 1988).

Since the open water-level fluctuations were temporally and spatially consistent across the entire study area, it is reasonable to expect that buoyant substrates in all zones had opportunities to exhibit vertical movement. Protracted, high water levels in the interior marshes from mid-July through mid-September, in addition to the occurrence of a Gulf tropical disturbance during this period, accounted for the majority of the mat movement we observed. The conditions of high water level during peak plant production and anaerobic metabolism, which enhances substrate gas accumulation, were conducive to mat movement. The lack of mat movement during the winter and early spring 1994-1995, indicates that the marshes in our study area maintain buoyancy usually during the growing season. Seasonal floatation of marsh mats is largely attributable to increased anaerobic metabolism in the substrate and increased aerenchyma development over the growing season (HOGG and WEIN, 1989; SWARZENSKI *et al.*, 1991). It is during the "grounded" condition of the marsh substrate, which usually occurs in the winter and early spring, that the marsh may be most susceptible to surface sedimentation (SASSER *et al.*, 1995). During these seasons, conditions for sediment transport are most favorable with increasing cold fronts (REED, 1989; ROBERTS *et al.*, 1989) and increasing Atchafalaya River discharge (higher sediment load).

In addition to documenting the vertical movement of oligohaline marshes near a large sediment source, we found that mineral sedimentation in these marshes was influenced mostly by large events, rather than average yearly river flooding. The most striking mineral sedimentation event in our cores was related to Hurricane Andrew, which impacted the study area in August 1992. The sediment layer deposited by Hurricane Andrew was evident in half of the 32 cores collected from this area. The western sites (near the river) received an average deposit of 10 cm of clays and silts overlying a distinct peat horizon; eastern sites (distant from the river) often did not contain storm sediments. GUNTENSPERGEN *et al.* (1995) found similar sedimentation patterns in this area with up to 16 cm of storm deposition near the edges of Atchafalaya Bay and lesser amounts inland. Another noticeable sedimentation event was detected in many of the western sites at an interval 20–25 cm below the pre-storm surface. Assuming a 1-cm per year vertical accretion factor for southern Terrebonne basin (NYMAN *et al.,* 1993b), we hypothesize this event was caused by the second largest flood of the century in 1973 followed by another massive flood in 1974 (Figure 6). That large events (tropical and cold front storms) are more important in vertical accretion than the average yearly over-the bank flooding is consistent with the findings of REMANEK *et al.* (1988), who showed that normal Atchafalaya River flooding (14% above the 30-yr average) contributed less to marsh accretion (<0.1 cm yr) than large events such as tropical storms: they found that Hurricane Danny (1985) was responsible for up to 2 cm of mineral sediment accretion. Mineral sedimentation in our study area seems to be an indirect process where sediments are deposited in open-water bays and channels, then resuspended and transported into interior marshes with storm surges (REED, 1989).

The general importance of mineral sedimentation in increasing marsh elevation—both indirectly (nutrient additions) and directly (accretion)—has been well documented (BRICKER-URSO *et al.,* 1989). The important role of intermittent, large sedimentation events, forced by cold front storms, in transporting sediments into coastal marshes also is well understood (REED, 1989; ROBERTS *et al.,* 1989; KEMP, 1986). Contrary to intermittent, large sedimentation events, the role of organic matter accumulation appears to be a continuous process that increases vertical marsh accretion, and this process was evident especially within the eastern marshes of our study area. The highly organic substrates in this area exemplify the findings that marsh substrate elevation is maintained autogenically (belowground root production and litterfall) (MCCAFFREY and THOMSON, 1980; NYMAN *et al.,* 1993a; CALLAWAY *et al.,* 1997; TURNER, 1997).

The imminent loss of coastal marshes in the northern Gulf of Mexico, and especially in the Louisiana deltaic plain, has received greater attention under the projection of continued sea level rise. The process of increased inundation of coastal marshes-caused by substrate subsidence and sea level rise-is known to be detrimental to plant health (MENDELSSOHN and MCKEE, 1988; MCKEE and MENDELSSOHN, 1989). Under persistent flooding, the marsh substrate is expected to become less stable with decreased root production, which increases the susceptibility of the substrate to erosion (DAY *et al.,* 1994), decomposition (DAY *et al.,* 1994) and collapse (NYMAN *et al.,* 1993a; DELAUNE *et al.,* 1994). Although this may be a plausible fate for much of the saline and brackish marshes in Louisiana, oligohaline and freshwater marshes with buoyant substrates may continue to adapt to subsidence and sea level rise.

In conclusion, the presence of non-buoyant marshes near the Atchafalaya River system and buoyant marshes with distance inland represent the extremes in a gradient of sediment deposition and organic matter production. Within this gradient, these non-exclusive mechanisms of marsh accretion and the maintenance of buoyant substrates may help offset losses in marsh elevation due to subsidence and sea-level rise.

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