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An equilibrium profile model for retreating marsh shorelines in southeast Louisiana

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A B S T R A C T

Louisiana's coastal marshes are experiencing the highest wetland loss rates in the U.S., in part due to subsidence-driven relative sea-level rise. These marshes are also vulnerable to the erosive power of wave attack: 1) on the marsh edge adjacent to open-water bodies, and 2) after the marsh platform is submerged. Marsh shorelines in Barataria Bay, Breton Sound, and the active Balize delta of southeastern Louisiana were examined in areas where the subaerial marsh platform had disappeared since 1932. Vibracore transects of marsh and adjacent bay surface sediments (to ~2 m depth) were analyzed using geotechnical, stratigraphic, and radiochemical (137-Cs and 210-Pb) methods, and the subaerial-to-subaqueous transition of the marsh was mapped for elevation using standard stadia rod transit and fathometer measurements. Results indicate that marsh edge erosion of the platform takes place subaqueously until water depths of ~1.5 m are reached. This is observed even in interior pond regions, but the shoreface elevation profiles are a function of fetch: exposed open bay sites display greater incision (depth and rate) of the marsh platform than protected interior bay or pond sites. Core stratigraphy reveals that the outer part of the subaqueous platform switches from erosional to depositional as retreat proceeds, covering the incised marsh deposits unconformably with estuarine shelly muds. 137-Cs and excess 210-Pb activity indicates that these muds are deposited within a few decades of subaerial marsh loss. The consistency of the cross-shore profile results suggests that a single profile of equilibrium can approximate the morphology of eroding marsh edges in southeast Louisiana: platform stratigraphy and resistance to erosion have a limited effect on profile shape. This equilibrium profile and remote sensing images of shoreline change are used to estimate the sediment yield to adjacent estuarine areas by this process. On average, 1.5 m^3 of sediment are yielded per m shoreline length annually from both Barataria Bay and Breton Sound. Due to the highly organic nature of the eroded sediment (~30%), this supply of organic-rich material could significantly impact estuarine productivity and hypoxia on the Louisiana continental shelf.

1. Introduction

In the presence of eustatic sea-level rise, understanding the processes of wetland deterioration is fundamental for mitigation of future losses and the current impact on coastal communities and infrastructure. Louisiana in the United States has some of the nation's highest wetland loss rates (26–30 km^2 yr^{-1}; Barras et al., 2003) which stems from natural factors such as subsidence from sediment compaction and dewatering, eustatic sea-level rise, wave erosion, growth faulting, isostatic adjustments, and halokinesis, as well as anthropogenic processes such as channelization of the Mississippi River, canal dredging, and fluid withdrawal (Coleman and Gagliano, 1964; Gagliano et al., 1981; Day et al., 2000; Gagliano, 2003; Morton et al., 2006). Marshes vertically accrete through *in situ* production of organic matter and detrital trapping in order to maintain an optimal elevation for production and sustainability (Delaune et al., 1983; Nyman et al., 1990; Cahoon and Reed, 1995). It has been shown in several studies of Louisiana deltaic marshes that accretion rates are insufficient to offset these rates of regional relative sea-level rise (RSLR; ~1–2 cm yr^{-1}; Baumann et al., 1984; Cahoon and Reed, 1995; Rybczyk and Cahoon, 2002).

Lateral retreat of the shorelines of bay, lake, and Gulf environments is estimated to account for 25% of overall wetland loss in Louisiana between 1932 and 1990 (Penland et al., 2000), thus horizontal shoreline changes are well-documented. However, little has been done to study the vertical shoreline morphology in this region. Kirby (2000) revealed that mudshore profiles generally reflect either the dominance of accretion or erosion: accretion-

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dominated shores are convex in shape, while erosion-dominated shores are concave. The shape is also controlled by tidal currents and, even more dominantly, by wave climate. The role of wave attack on coastal marshes is compounded by the conversion of marsh platforms to open-water, thereby increasing the fetch and wave power on exposed marsh edges. Alteration of marsh edge bathymetric gradients increases waterbody depth adjacent to the marsh platform. This likely impacts the rate of loss of remaining subaerial marshes (an increase in the wave power would increase the retreat) and would increase the sediment volume needed to rebuild wetland habitat with restoration efforts.

The primary objective of this study was to identify the nature and magnitude of wave-induced subaqueous platform erosion that takes place with retreat of the marsh shoreline in several study areas in southeastern Louisiana. We formulate a conceptual model that addresses this retreat with RSLR. We find that, contrary to a previous study by Kirby (2000), marsh shorelines in coastal Louisiana are erosion-dominated and unstable and yield significant material into the adjacent bays with their rapid retreat ($\sim 1\ \mathrm{m\,yr^{-1}}$ in the study areas). Quantification of the volume of mineral and particulate organic matter (POM) released by erosion of the marsh platform is critical because it supplies nutrients to macrofauna and flora in adjacent estuarine water bodies, is a potential contributor to summer hypoxia on the adjacent inner continental shelf (Bianchi et al., 2007), and is an undervalued source of organic matter flux in carbon budgets.

2. Study areas

The Mississippi deltaic plain is a result of the deposition and reworking of sediments carried by the Mississippi River, which has changed course at least five times since eustatic sea-level stabilized in the northern Gulf of Mexico about 7000 yr BP (Frazier, 1967; Roberts, 1997; Coleman et al., 1998). In this study we investigated marsh systems formed by three different deltaic lobes (Fig. 1). The first site was in the St. Bernard delta lobe, which was active between ~3700 year BP and ~1500 yr BP east of the modern river course (Törnqvist et al., 1996). Field sites in Breton Sound were chosen in three *Spartina alterniflora*-dominant marsh areas labeled IBS, or Inner Breton Sound.

The second study site was Barataria Bay, which occupies an interlobe basin between the modern Balize and abandoned Lafourche delta lobes (active ~1500–100 yr BP, and ~1300 yr BP to present, respectively; Frazier, 1967; Törnqvist et al., 1996; Flocks et al., 2006). Barataria Basin peat deposits began forming 400 yr BP when clastic deltaic sediments from the modern Balize delta lobe bypassed the area (Kosters, 1989). Compaction and subsidence of underlying deltaic deposits has contributed toward shoreline transgression, and currently both Barataria Bay and Breton Sound are in a similar state of deterioration (large land areas have converted to open-water). Field studies were conducted in *S. alterniflora* marshes in both the upper and lower Barataria Bay (UBB and LBB, respectively; Fig. 1).

The third site is in the Balize lobe of the modern river course. Although the Balize delta continues to actively receive freshwater and sediment from the Mississippi River through minor distributaries and crevasses and by overbanking of natural levees during high discharge periods, submergence and wetland deterioration take place on now moribund crevasse splays formed during the last 1–2 centuries (Wells et al., 1982). Three field sites were examined in *Panicum hemitomon* (maidencane) dominated wetlands located in the Deltas National Wildlife refuge (DNWR; Fig. 1).

3. Methods

Field areas were chosen using georeferenced wetland loss images created by Penland et al. (2000), and representative study

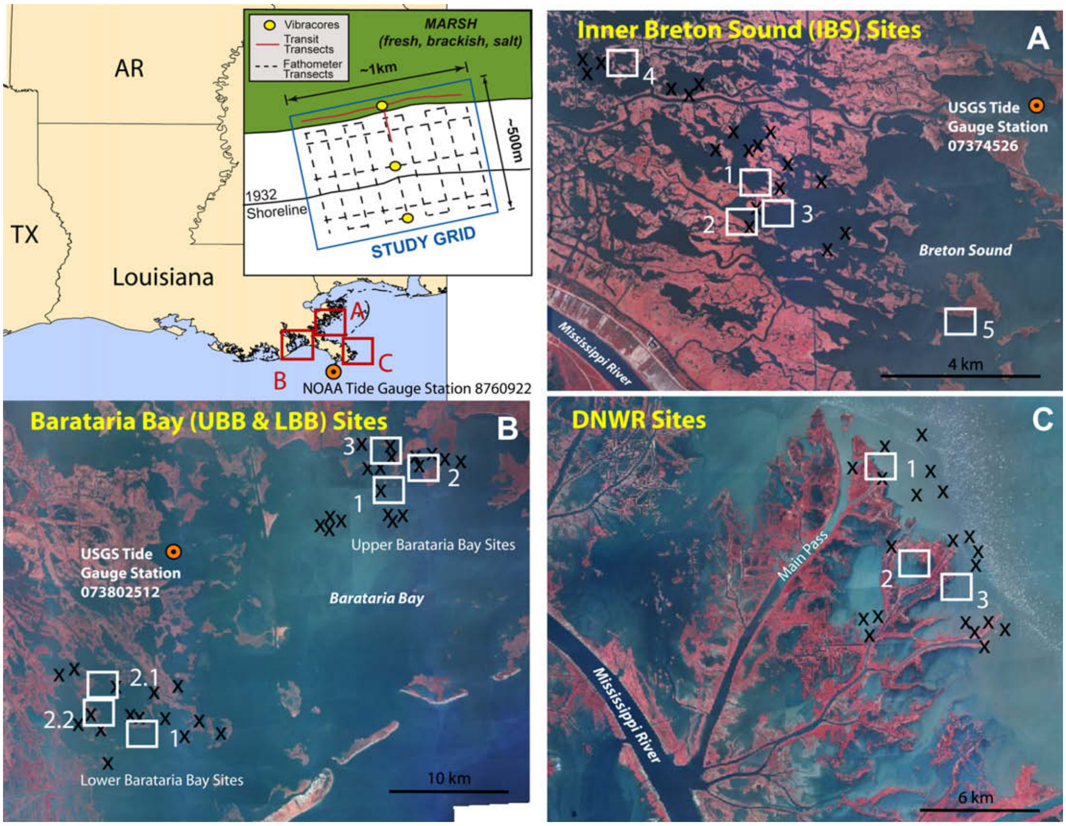

Fig. 1. Study areas including locations of study grids occupied and local tide gauges. *X*'s mark locations of oil and gas wells within a 4 km radius of the study areas (from SONRIS, Louisiana Department of Natural Resources).

sites were identified for bay-fronting, Gulf-fronting, and interior pond areas that had experienced marsh loss between 1932 and 1999 surveys. Grids ~1 km × 500 m were established in each study site, and a minimum of three grids were occupied in each of the three-study areas (Fig. 1). The placement of multiple sampling grids at each site was designed in order to capture a variety of shoreline orientations to predominant wave approach and fetch. Within each grid, elevation data of the marsh surface and adjacent subaqueous platform (mudflat) were established, vibracores were acquired from the marsh shoreline and along a central transect at two distances offshore, and bathymetry was determined for the submerged grid areas (Fig. 1).

3.1. Topographic and bathymetric surveys

Elevation data were collected with an electronic theodolite and stadia rod (±1 cm vertically). Marsh elevations were taken ~15 m apart alongshore, and shore-normal approximately every meter from the marsh edge to 5 m offshore, then every 5 m to the location of the outer vibracore site. Elevations are reported here relative to the marsh edge elevation (measured by transit data), which were converted to NAVD 88 using as a calibration point the elevation of the water surface compared with local tide gauge records (USGS station 073802512 for Barataria Bay, USGS station 07374526 for Breton Sound, and NOAA station 8760922 for DNWR sites, Fig. 1).

Bathymetric maps were made with a 200 kHz Odom shallow water fathometer. Transects were made in both alongshore and shore-normal directions (5–10 per grid) at speeds of <0.5 m/s. Bayfloor elevation measurements were converted to NAVD 88 and then established relative to the marsh edge using the approach mentioned above. Plotting NAVD-corrected fathometer and core elevation data with stadia rod transit data revealed noticeable offsets in the best-fit shoreface elevation profile across some of the sites. This offset was restricted to sites >10 km from the tide gauge and likely resulted from a time lag in progression of the diurnal tide in the estuaries. Offsets were corrected by equalizing the elevation determined for a core location using the transit measurements and that determined using water depth and tide gauge data.

3.2. Sedimentology and geotechnical analyses

Stratigraphy to ~2 m below the sediment surface was analyzed and correlated using 7.5 cm diameter vibracores (41 total, 14 marsh and 27 offshore; locations in Table A Supplemental Material). Top of core elevation was determined relative to NAVD 88 and then converted to elevation relative to the marsh edge. The possibility of core shortening and rodding was assessed by measuring inside and outside the barrel prior to extraction, and the elevations of stratal boundaries were corrected assuming uniform downcore compaction through the entire core.

Cores were cut lengthwise, described for stratigraphy, and X-rayed at 40-cm overlapping intervals using a portable X-ray unit operating at 66 kV/50 mA. Shear strength measurements were obtained at 10 cm depth intervals in one core half using a hand-held shear vane tester (range 0–200 kPa). The other half of the core was subsampled at 2 cm intervals every 5 cm to a depth of 100 cm, and 2 cm every 10 cm thereafter. Samples were then frozen for storage prior to further analysis. Marsh and offshore core sample aliquots were freeze-dried and reweighed to determine water content and porosity. For the 13 marsh cores and a few offshore cores, a separate sample aliquot of ~10 g of freeze-dried sediment was homogenized with a mortar and pestle, and weight loss on ignition was performed (550 °C in a muffle furnace for 14 h) to yield percent organic matter as a function of depth.

3.3. Radiochemical analyses

Activities of ^{137}Cs and ^{210}Pb with depth were measured using a low-energy germanium γ-spectrometer to examine the timing and rates of sediment accumulation on the marsh surface and in the bay environments offshore. Both coaxial planar and well-type detectors were used dependent on sample size (all samples from a single core were counted by one detector type). Freeze-dried sediment samples were ground, packed in either 50 mm diameter Petri dishes (planar geometry) or 60 mm long test tubes (well geometry), sealed to prevent ^{222}Rn loss, and allowed to ingrow to secular equilibrium for ^{210}Pb for at least three weeks. Samples were then counted for 1–2 days. Activities were calculated following the methods outlined in Allison et al. (2007). A best-fit linear regression of the natural log of excess ^{210}Pb (^{210}Pb$_{xs}$) with depth below any surface mixed layer of homogenous activity was used to determine the sediment accumulation for the past ~100 years (Nittrouer and Sternberg, 1981). ^{137}Cs ($T_{½} = 30$ year) is the product of fallout from atmospheric testing of thermonuclear weapons that began in 1954. Two time markers for ^{137}Cs with depth were utilized: the depth of maximum ^{137}Cs penetration (1954) and the depth of maximum ^{137}Cs activity in the northern hemisphere (1963 according to Chmura and Kosters, 1994).

4. Results

4.1. Eroding marsh shoreline and shoreface topography

Topography of the subaerial marsh platforms is fairly uniform, averaging ± 12 cm relative to the marsh edge. The sites with the most and the least alongshore variability were Site LBB 2 (+0.08 to −0.49 m relative to the marsh edge) and Site IBS 3 (+0.11 and +0.0 m relative to the marsh edge), but for the most part the marsh platforms are relatively flat. The shore-normal profiles of the first site measured, LBB 1, display a vertical scarp 30–50 cm high, and the offshore mudflat is concave in shape with slopes gradually decreasing to 1.0–1.5 m depth below the marsh surface, reaching a horizontal platform that extends at least 300 m from the marsh edge. Almost all of the sites in all three-study areas display this same trend (see Fig. 2 for LBB 1, UBB 1, IBS 4, and a compilation of all study areas). Exceptions to this trend are sites UBB 3, IBS 1, and DNWR 2. UBB 3 and IBS 1 are adjacent to marsh channels or bayous in Barataria Bay and Breton Sound (Wilkinson Bayou and Baker's Bay, respectively), and DNWR 2 displays a unique profile with a horizontal subaqueous marsh surface and offshore platform 1.0 m in depth. Fathometer measurements across multiple shore-normal transects have little spatial variability (typically ±10 cm) and the offshore bathymetry is relatively uniform.

4.2. Core stratigraphy and sedimentary properties

Core lengths of the 41 vibracores ranged between 1.80 and 2.72 m. Cores collected offshore of the subaerial marsh shoreline were taken in water depths ranging from 0.81 to 1.82 m. Table A in Supplemental Material summarizes the field data observations that were collected at each coring location. Distinct sedimentary facies were identifiable basin-wide in the vibracores and have been documented throughout southeast Louisiana estuarine basins (e.g., Coleman and Gagliano, 1964; Kosters, 1989; Morton et al., 2003). These facies are referred to hereafter as: 1) *Organic-rich Mud and Peat*, 2) *Massive Mud*, 3) *Interbedded Sand and Mud*, and 4) *Shelly Bay-bottom Mud* (see Table 1 for facies descriptions). Throughout all of the study sites these facies are arranged in a similar stratigraphic order.

At the Barataria Bay and Breton Sound sites, marsh cores typically contained *Interbedded Sand and Mud* extending to the base of

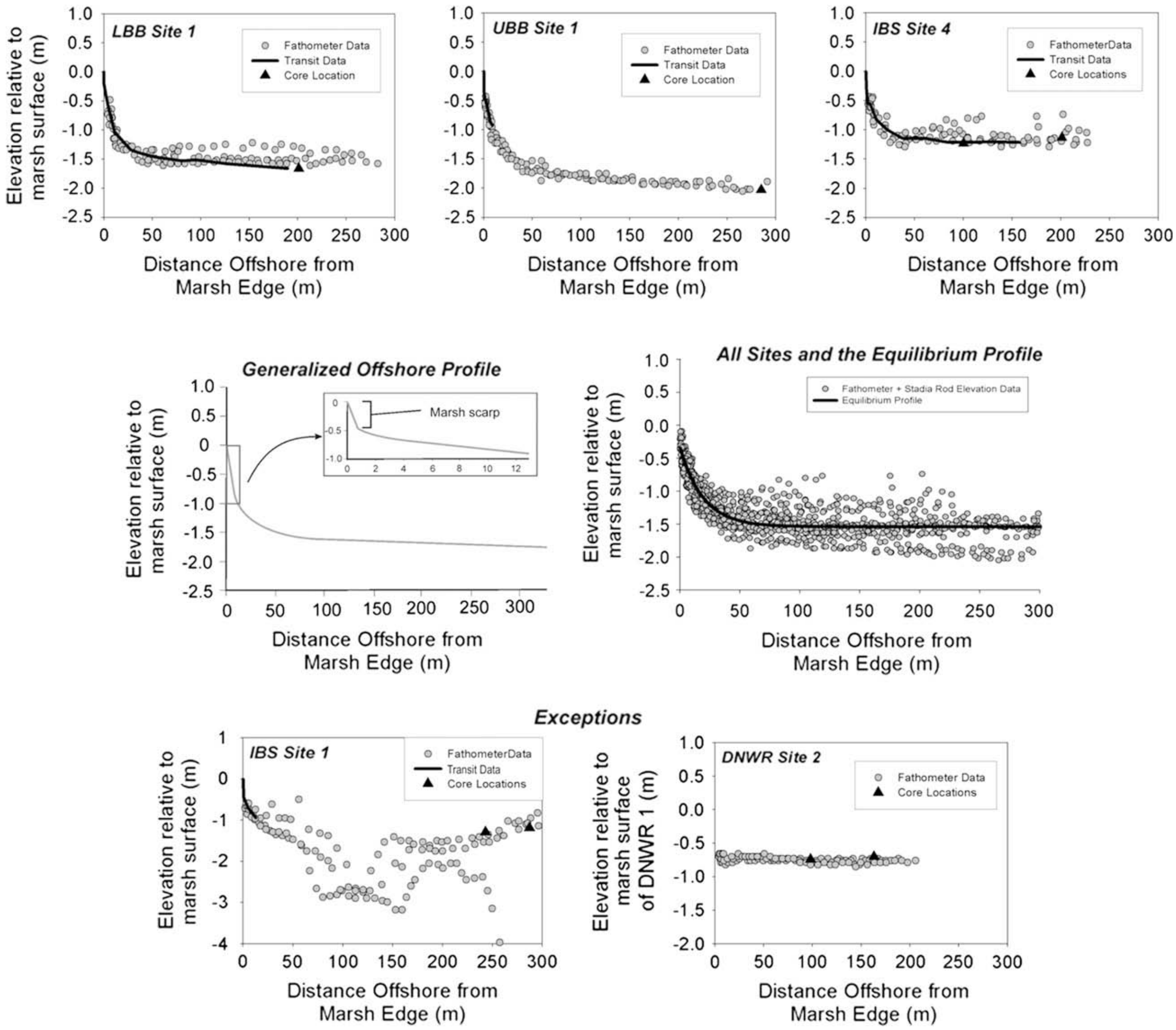

Fig. 2. Offshore elevation profiles measured for Lower Barataria Bay (LBB) Site 1, Upper Barataria Bay (UBB) Site 1, and Inner Breton Sound (IBS) Site 4 (*top*). Diagram of generalized offshore profile found in most study grids and the equilibrium profile produced by all fathometer and transit measurements (*middle*), and two notable exceptions to the elevation trends, IBS 1 and DNWR 2 (*bottom*).

Table 1
Sedimentary facies descriptions, properties, and basins found for this study

Facies	Description	General thickness (cm)	Shear strength ranges (kPa)	Porosity ranges (%)	Organic matter ranges(%)	Basins found
Organic-rich Mud and Peat	Brown to gray organic-rich, usually fine-grained sediment (clay t silty clay) matrix permeated by roots (*spartina* sp.) that grades into a more compact, organic-rich brown to black peat.	150–200	0–18 avg. = 3.5	53.1–94.2 avg. = 83.6	3.4–82.4 avg. = 31.8	BB BS DNWR
Massive Mud	Olive gray mud with little organic content and little root traces. Massive appearance suggests extensive bioturbation.	20–100	0–12 avg. = 3	51.1–87.8 avg. = 69.7	4.3–22 avg. = 10	BB BS DNWR
Interbedded Sand and Mud	Horizontal mud and sand beds and laminations. Mud deposits are usuallyolive to greenish gray, although some may be yellowish to tan in color. The sand (typically fine to silty sand) is also usually olive to greenish gray. No roots or organic content is present, although shells of either estuarine clams (*Rangia* sp.) or oysters (*Crassostrea* sp.) may be present.	50–>200	0–24 avg. = 38.8	51.3–63.4 avg. = 56.2	2.4–8.0 avg. = 4.6	BB BS DNWR
Shelly Bay-bottom Mud	Typically composed of silty mud to muddy sand and frequently has shell fragments (*Rangia* sp.) throughout. Colors vary between light gray, brownish gray, olive gray, dark greenish gray, and olive black. Displays an erosional basal surface with underlying sediments of the Organic-rich Mud and Peat facies.	10–150	0–14 avg. = 3.2	53.9–80 avg. = 67.9	N/A	Barataria Bay Breton Sound

vibracores (but was at least 50–171 cm thick) overlain by *Massive Mud* (8–162 cm thick) capped with *Organic-rich Mud and Peat* (101–207 cm thick; Fig. 3). For example, the marsh core at LBB 1 had 119 cm *Organic-rich Mud and Peat* overlying 75 cm *Massive Mud*, and 52 cm *Interbedded Sand and Mud* at its base. In the cores collected from adjacent bay and pond environments of these two study sites, all three of these facies are present below *Shelly Bay-bottom Mud* that forms the top strata of the cores and is separated from underlying facies by an erosional surface (Fig. 3). The thickness of the *Shelly Bay-bottom Mud* (6–154 cm) thickens with distance from the marsh shoreline. The thickness of *Organic-rich Mud and Peat* (8–80 cm) below the *Shelly Bay-bottom Mud* thins bayward in contrast (presumably due to erosion), but is sedimentologically similar to its marsh counterpart.

Vibracore samples from the DNWR were significantly different from the facies patterns from Barataria Bay and Breton Sound (Fig. 3). The marsh cores in this *Panicum*-dominated environment display a much less laterally extensive and less organic-rich *Organic-rich Mud and Peat* facies. For example, the marsh core for Site 1 (DNWR 0105-1) had only ~5 cm of roots and organic-rich sediment, and the marsh core for Site 2 (DNWR 0105-4) had roots visible to only 14 cm depth. Below this, however, the marsh cores contained downcore succession from *Massive Mud* to *Interbedded Sand and Mud*, similar to the Barataria Bay and Breton Sound cores. The cores collected in the pond and gulf environments of the DNWR varied from the Barataria Bay and Breton Sound sites as well: *Shelly Bay-bottom Mud* was absent in all DNWR cores. Instead, the offshore cores of Sites 1 and 3 (DNWR 0105-2, DNWR 0105-3, and DNWR 0800-2) contained *Interbedded Sand and Mud* throughout, and the pond cores of Site 2 (DNWR 0105-5 and DNWR 0105-6) display *Massive Mud* overlying *Interbedded Sand and Mud* (Fig. 3). No erosional surface is evident in any of the offshore cores, although aerial imagery reveals shoreline retreat.

The sedimentary facies described above have distinct bulk properties for porosity, shear strength, and organic matter content (Table 1). Comparison between the study areas reveals surface sediments from the DNWR possess separate distinct bulk properties: organic content and porosity is much lower (~8% and 65%, respectively), and shear strength much higher (~6 kPa) than Breton Sound and Barataria sites (averaging 29% for organic content, 81% for porosity, and 3 kPa for shear strength; Table 2).

4.3. Core ^{137}Cs and ^{210}Pb radiochemistry

^{137}Cs activity with depth displays downcore profiles of two types. In the first type (Type A), a downcore ^{137}Cs peak in activity is easily discernable, whereas in the second the downcore trend shows no distinct peak (Type B; Fig. 4). For Type A cores, ^{137}Cs accumulation rates were calculated for this horizon assuming it represented the 1963 peak in atmospheric hydrogen bomb testing, and for the depth of ^{137}Cs penetration, marking the onset of testing (1954). For Type B, only depth of penetration was utilized to calculate accumulation rates.

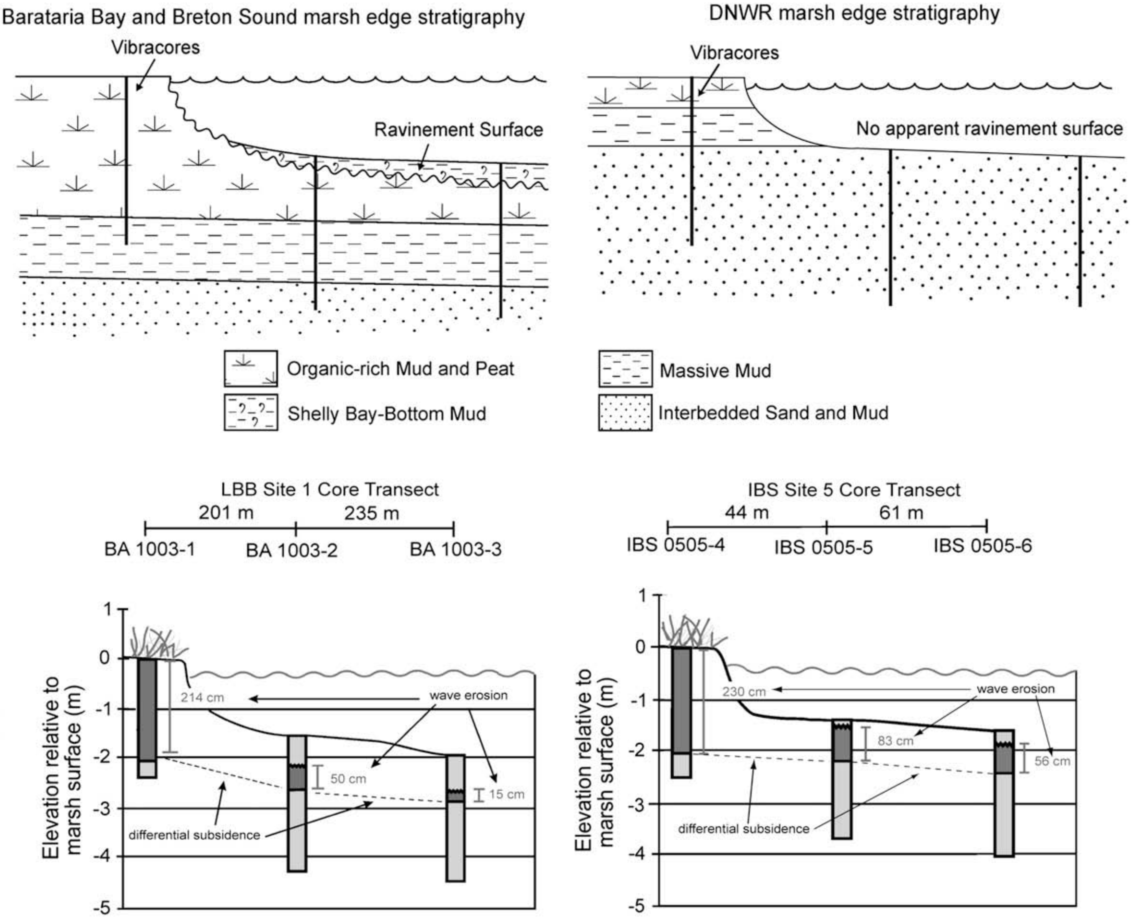

Fig. 3. *Top*-Idealized diagram of eroding marsh shoreface stratigraphy in Barataria Bay and Breton Sound versus the DNWR. Approximate locations of the three vibracores collected for each site are indicated. *Bottom*-Offset and thickness of the *Organic-rich Mud and Peat* facies (demarcated by brackets) in the marsh core and the two cores taken in the bay/pond environment were used to assess the relative importance of wave erosion and differential subsidence (see Table 3).

Table 2
Comparison of sedimentary properties between cores taken in the marsh and bay environments in Lower Barataria Bay (LBB), Upper Barataria Bay (UBB), Inner Breton Sound (IBS), and Deltas National Wildlife Refuge (DNWR) study areas

	LLB	UBB	IBS	DNWR
Marsh cores				
Porosity (%)	51–91 avg. = 77	55–94 avg. = 83	51–94 avg. = 83	51–84 avg. = 67
Shear strength (kPa)	–	0–10 avg. = 2	0–18 avg. = 4	0–18 avg. = 5.6
Organic matter (%)	2–76 avg. = 22	5–74 avg. = 34	2–82 avg. = 31	2–22 avg. = 8
Bay cores				
Shear strength (kPa)	–	0–16 avg. = 4.5	0–24 avg. = 5.4	0–22 avg. = 7.3

Three patterns were observed in the downcore profiles of ^{210}Pb activity (Fig. 4). In Type I, ^{210}Pb$_{xs}$ activity decreases logarithmically with depth below a shallow (5–10 cm) surface mixed layer, indicating a relatively steady-state accumulation rate (core BA 0604-3 for UBB 3, Fig. 4). In Type II, ^{210}Pb$_{xs}$ activity either decreases to zero immediately below the 0–2 cm interval or is not present at all, indicating a sediment age greater than the threshold of ^{210}Pb dating (~100 year; core BA 1003-3 for LBB 1, Fig. 4). In Type III, downcore activities vary randomly with depth such that no accumulation rate can be determined (core DNWR-1 for DNWR 1, Fig. 4). These sites show major variations in porosity and X-ray density with depth, suggesting layers of distinctly different grain size which impacts ^{210}Pb activity because it is predominantly adsorbed onto clays.

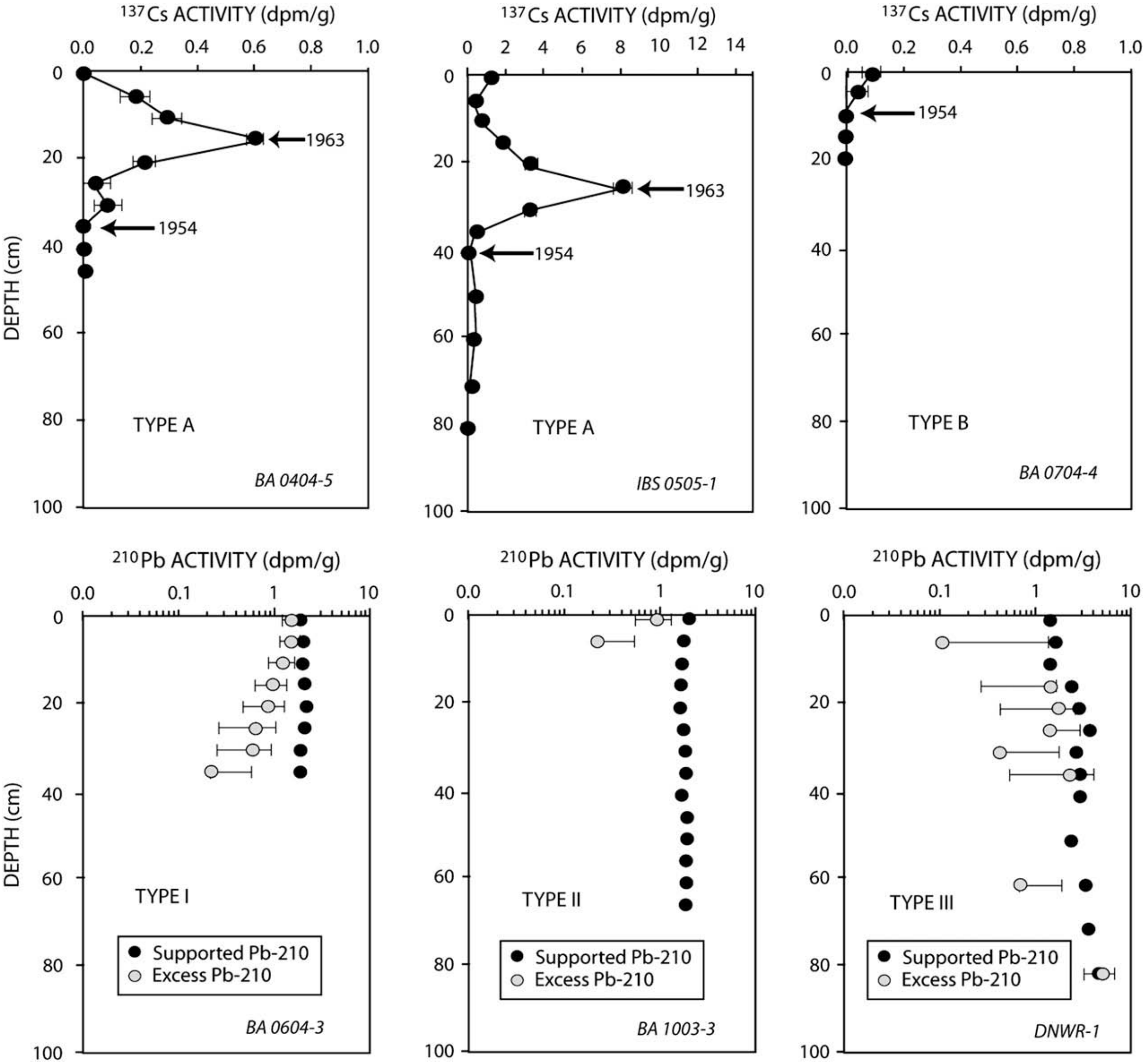

Fig. 4. Downcore trends in ^{137}Cs (*top*) and ^{210}Pb (*bottom*) activity for the two Cesium and three Lead profile types described in the text.

Barataria Bay and Breton Sound marshes had similar accumulation rates with some site-specific variability, averaging 0.67 ± 0.49 cm yr^{-1} and 0.80 ± 0.17 cm yr^{-1}, respectively (Table B in Supplemental Material summarizes the ^{137}Cs and ^{210}Pb accumulation rates for the cores). DNWR marshes had the highest accumulation rates, with both marsh sites >1.59 cm yr^{-1} (for many DNWR cores rates are reported as minima, as ^{137}Cs activity was found at the base of the vibracore). Marsh sites adjacent to large, open-water bodies generally have higher accumulation rates than marsh sites adjacent to small and relatively enclosed water bodies. For example, LBB Site 1 has an average marsh accumulation rate that is 150% higher than LBB Site 2.1 (1.38 cm yr^{-1} compared to 0.54 cm yr^{-1}). Barataria Bay and Breton Sound bay or pond cores had lower average accumulation rates than DNWR gulf and pond cores (1.41 ± 0.26 cm yr^{-1} in the DNWR versus 0.48 ± 0.16 cm yr^{-1} and 0.59 ± 0.50 cm yr^{-1} in Barataria Bay and Breton Sound, respectively).

5. Discussion

5.1. Development of sedimentary facies

5.1.1. Barataria Bay and Breton Sound

The stratigraphic sequences observed in the Barataria Bay and Breton Sound cores are characteristic of Holocene progradational deposits described previously for the Louisiana lower deltaic plain (Coleman and Gagliano, 1964; Kosters, 1989; Morton et al., 2003). The upward-fining sediment sequence is indicative of a transition from 1) delta-front deposits, to 2) the shoaling of an interdistributary/interlobe waterbody, to 3) the establishment of a subaerial marsh. The *Interbedded Sand and Mud* facies found in the deepest sections of the core samples represents delta-front deposits when the area was dominated by direct riverine sediment input (see Fig. 3). The *Massive Mud* facies overlying the *Interbedded Sand and Mud* characterizes deposition in a quiescent, shoaling interdistributary or interlobe waterbody once active lobe deposition bypassed the area. Finally, the *Organic-rich Mud and Peat* facies represents subaerial marsh development once elevations aggraded sufficiently to support plant colonization.

Studies have shown that the organic-rich mud and peat in both Barataria Bay and Breton Sound are horizontally continuous over short (<1 km) distances (Coleman and Gagliano, 1964; Kosters, 1989; Dharmasri, 1998). Assuming lateral continuity of peat horizons, the peat deposits found in cores taken in the offshore field sites were once continuous with those in the marsh cores, which is supported by shoreline edge retreat observed in aerial imagery (Penland et al., 2000). Because a sharp contact, interpreted as an erosional ravinement surface, exists between these deposits and the overlying *Shelly Bay-bottom Mud* in the offshore cores and the marsh shoreline displays an erosional vertical scarp, the strata of the offshore bay environments in these areas are interpreted to form as a result of wave incision coupled with possible RSLR. The subaerial marsh deposits (*Organic-rich Mud and Peat* to ~1.5 m depth) are progressively removed by erosion with continued retreat of the marsh edge. However, rapid RSLR creates accommodation space and incision rates decrease toward the base of the shoreface, allowing a transition to the accumulation of estuarine bay-bottom sediments (*Shelly Bay-bottom Mud*) on top of the remaining *Organic-rich Mud and Peat* facies as predicted by Coleman and Gagliano (1964) (Fig. 3).

5.1.2. The DNWR

The study grids from the DNWR are located in the Cubit's Gap subdelta complex of the Balize delta (Fig. 1). This subdelta formed as a crevasse splay from an 1862 man-made break in the Mississippi River that prograded northeast onto the continental shelf during the next several decades (Wells et al., 1982). The freshwater *Panicum* marsh is presently receiving freshwater and sediment from the Mississippi River, indicated by rapid sediment accumulation rates of 1.3 to >1.59 cm yr^{-1} in the marsh, gulf, and pond settings (Supplemental Material Table B). In spite of these high rates, all the Balize lobe subdeltas such as Cubit's Gap have undergone significant wetland deterioration in recent decades due to interior ponding (Penland et al., 2000), compounded recently (2005) by Hurricane Katrina wave erosion of Gulf-facing marsh edges (Barras, 2006). The presence of thin *Organic-rich Mud and Peat* facies in the marsh cores (~5–15 cm of roots, no true peat) supports an earlier study (Kosters, 1989) which noted that organic lithofacies of interdistributary bays in the Balize delta would be thin and poorly developed due to the daily flushing from the river. The sedimentology in all of the DNWR cores is dominated instead by the *Interbedded Sand and Mud* from active riverine deposition and crevasse splay deposits (delta-front facies).

For Gulf-fronting DNWR sites, lateral retreat of the marsh surface from wave incision would completely remove any *Organic-rich Mud and Peat*. Indeed, the three offshore cores for these sites lack this facies and solely contain *Interbedded Sand and Mud* (Fig. 3). For Interior Pond sites, the similar lack of *Organic-rich Mud and Peat* in the pond cores indicates that any organic material from the marsh that occupied the area prior to 1932 has been eroded and flushed, either from river discharge as predicted by Kosters (1989) or possibly from tidal scour since the marsh surface is subaqueous. Instead, a *Massive Mud* facies is present at the surface of the pond cores that ^{137}Cs and ^{210}Pb radiochemistry indicates is the result of recent riverine delivery and deposition in the quiescent pond environments (accumulation rate of 1.41 ± 0.26 cm yr^{-1}).

5.2. Relative importance of erosion and subsidence on shoreface evolution

Assuming laterally continuous peat deposits, elevation and thickness differences of the *Organic-rich Mud and Peat* facies in the three shore-normal cores at each site can be used to estimate relative importance of post-depositional subsidence and wave erosion at each site. For each Breton Sound and Barataria grid, the amount of surficial erosion in the shoreface profile was determined by comparing the thickness of the *Organic-rich Mud and Peat* between the marsh site and each of the two offshore cores, assuming originally equal thickness across the few 100 meters of their offset (Fig. 3). Differential subsidence was determined by comparing the depth to the upper contact of the *Massive Mud* facies in each of the cores and assuming that the onset of marsh deposition was relatively synchronous over these spatial scales (Fig. 3). This approach has been used in other studies (e.g., Morton et al., 2003). It should be noted, however, that the amount of surficial erosion is a maximum since organic and mineral accumulation continued at the marsh coring site even after submergence and erosion of the adjacent marsh platform, resulting in a thicker organic facies deposit in the marsh core than would be originally present in the offshore cores. In addition, we use the terminology *differential subsidence* because general regional subsidence is presumably affecting the entire region (Penland and Ramsey, 1990; Meckel et al., 2006) but differential subsidence encompasses the spatial variability of this apparent subsidence within the study grids. This could be a result of different underlying geology at depth or hydrocarbon withdrawal.

The combined processes of wave erosion and differential subsidence result in submerged marsh platform elevation deflation. In Barataria Bay and Breton Sound, wave erosion accounted for the majority of the deflation (63% and 72% of the elevation loss, respectively), while differential subsidence accounted for the remainder (37% in Barataria and 28% in Breton Sound; see Table 3). In the DNWR, where a well-defined organic-rich marsh layer is absent, the above analyses are not possible. However, wave incision of ~50 cm can be inferred at one site, DNWR 3, by matching ^{210}Pb exponential decay profiles in the marsh core and offshore core. At another site (DNWR 2, an interior pond site) the *Panicum* cane was submerged on a platform of ~1 m depth that extended >300 m into the pond (Fig. 2). The uniformity of this profile suggests a more invariant regional subsidence, possibly reflecting that the compaction of the thick Holocene sediments (~150 m) in this young subdelta of the Mississippi River is the main factor in the marsh loss at this site.

Results of this study relative to work in Madison Bay, Louisiana by Morton et al. (2003) indicate that wave erosion is a larger factor causing marsh platform deflation (Table 3). The greater exposure in Barataria Bay and Breton Sound study areas likely influences this because Madison Bay is more inland and protected. Differential subsidence in the Madison Bay area was across a larger lateral distances (several km's) and was ascribed to locally accelerated subsidence above a former oil and gas field (Morton et al., 2006). The present results suggest that significant differential subsidence (>50–100 cm) appears to have taken place regionally in the lower delta at sites, proximal as well as distal to hydrocarbon wells (see Fig. 1).

Caution must be exercised with the results of the subsidence analysis in this study. If the peat was *not* horizontally continuous, the offset observed between the marsh core and offshore counterparts could be explained by differences in elevation of the surface of marsh growth, and hence, in the timing of onset of peat deposition. To eliminate this possibility, radiocarbon dates of the basal peats would be required. The presence of an original slope across which the basal marsh deposits form would also increase the apparent differential subsidence in the above calculations. Another concern is that core compaction may not be uniformly partitioned over the different facies through which the core is passing. Variability in the shear strength suggests that susceptibility to compaction may be non-uniform, with weaker intervals such as the *Organic-rich Mud and Peat* undergoing the majority of compaction. However, little has been done to date to ascertain the compaction variability of different stratigraphic layers in the Mississippi deltaic plain, and it was not the focus of this study.

5.3. *A conceptual model of marsh shoreline evolution in South Louisiana*

Traditionally, the concave-upward shape of sandy, ocean-fronting shorefaces have been described in terms of an equilibrium profile. The profile is steepest at the shoreline and has a progressively decreasing offshore slope (Komar, 1998). Only recently has the concept of a shoreface equilibrium profile been applied to muddy coasts, and studies suggest that a mudflat profile is concave-upward where it is erosional (Kirby, 2000; Woodroffe, 2003).

Table 3
Calculated subsidence and erosion at various sites using core transects as illustrated in Fig. 3

Site	Subsidence (cm)	Erosion (cm)
LBB 1	97 (33%)	199 (67%)
LBB 2.1	132 (38%)	211 (62%)
LBB 2.2	117 (34%)	227 (48%)
UBB 1	201 (52%)	183 (74%)
UBB 2	60 (26%)	168 (75%)
IBS 2	74 (25%)	220 (75%)
IBS 3	95 (32%)	198 (68%)
IBS 4	71 (41%)	101 (59%)
IBS 5	28 (14%)	174 (86%)
Barataria Bay average	121	199
Breton Sound average	67	173
Madison Bay[a] range and average	53–92 Avg = 69	2–34 Avg = 25

[a] From Morton et al. (2003).

For sandy shorefaces, Bruun (1962) outlined the effect of RSLR on beaches that had attained an equilibrium profile. RSLR would cause erosion and lateral retreat of the upper beach, and this sediment would be transported to the adjacent seafloor, causing aggradation. Ultimately, the profile of equilibrium slopes would be preserved, having merely migrated upward and landward, and sediment eroded from the shoreface would account for offshore deposition (Komar, 1998). Kirby (2000) introduced a similar concept for mudshores (the Mehby Rule), however it postulated that the majority of material eroded from the marsh edge is lost offshore as opposed to deposited on adjacent mudflats. In addition, Kirby (2000) formulated a mudshore stability model that identified Louisiana shorelines as generally stable and accreting. Our results clearly contrast Kirby's findings: an erosional profile of equilibrium is ubiquitous on marsh shorelines in southeastern Louisiana, particularly in Barataria Bay and Breton Sound (Fig. 2). Additionally, significant material eroded from the retreat of these shorelines is likely a component of the proximal *Shelly Bay-bottom Mud* deposit.

Statistically, the marsh shoreface profiles in Louisiana fit an exponential decay regression curve with the equation:

$$y = -1.5 + 1.2e^{(-0.05x)} \qquad (1)$$

The r^2 value of this regression was 0.75 (see Fig. 2). Because this pattern is apparent throughout Barataria Bay and Breton Sound, this suggests that variations in sediment strength have a minor influence on the nature of the eventual offshore elevation profile. Consequently, wave climate is presumably the primary factor determining the general shape of the profile. Overall, Barataria Bay and Breton Sound share a similar wave climate (typically wave heights of 0.07–0.8 m, although tropical cyclones can cause waves in excess of 2 m in height with their associated storm surge; Georgiou et al., 2005; Stone et al., 2005). More significant differences appear to be related to fetch and exposure to predominant directions of wave approach. Sites in shallow and protected interior bays with little fetch (e.g., Sites IBS 4, UBB 2) display a much shallower offshore profile than sites that occupy larger and deeper bays with greater fetch and exposure to wave attack (Sites UBB 1, LBB 1; Figs. 1 and 2).

According to Bruun (1962), maintaining a shoreface profile of equilibrium with RSLR requires that sediment eroded from the marsh edge is deposited in the adjacent open-water environment (Komar, 1998). This process, along with the lateral retreat of this profile upward and landward, explains the stratigraphy in the study grids at Barataria Bay and Breton Sound. As the profile translates upward and landward with RSLR, thicker peat deposits are preserved closer to the present marsh shoreline whereas, in the outer profile, the erosionally thinned peat layer is capped by the *Shelly Bay-bottom Mud* facies that thickens offshore (Fig. 3). However, the latter unit is likely not only sourced from erosion of adjacent marsh fringe. Material from the Mississippi River could be transported into the bays (e.g., through Barataria Pass in Barataria Bay), particularly during major storm events.

We propose a conceptual model to describe fringing marsh shoreline evolution with respect to the translation of an equilibrium profile in southeast Louisiana (Fig. 5). Studies have shown that while marshes can maintain elevation if accumulation rates are equal to or higher than the rate of RSLR (e.g., Baumann et al., 1984; Rybczyk and Cahoon, 2002), they are still subject to erosion and retreat from wave attack, particularly if the nearshore sedimentation rate is less than the rate of RSLR (Schwimmer and Pizzuto, 2000). As subaerial marshes become submerged due to RSLR,

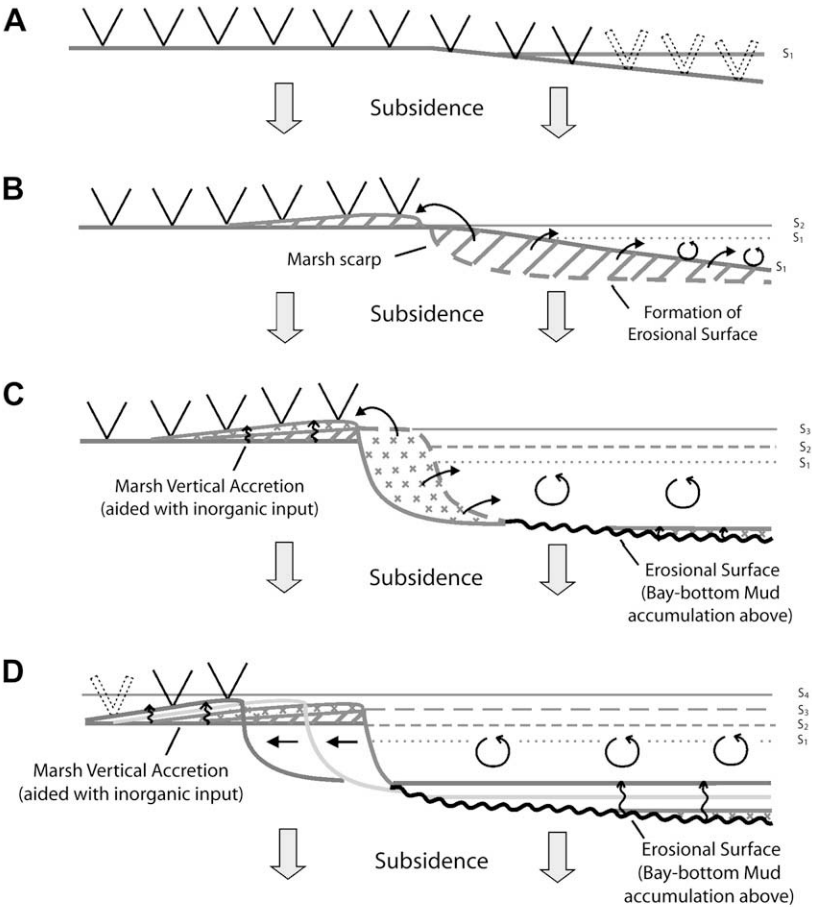

Fig. 5. Conceptual model of the fringing marsh shoreline evolution with respect to the translation of an equilibrium profile with RSLR in southeast Louisiana. See text for detailed explanation.

increases in water depth increase the wave power reaching the marsh edge (Schwimmer and Pizzuto, 2000; Fig. 5-A). Wave attack laterally incises the marsh surface, causing its retreat and the formation of a marsh scarp, as well as a reduction in the thickness of surficial *Organic-rich Mud and Peat* facies and development of an erosional hiatal surface (Fig. 5-B). With continued RSLR and upward/landward shoreface profile translation, the depth of the submerged marsh platform reaches a threshold where waves no longer impact the bay-bottom and processes are no longer erosional (~1.0–1.5 m water depth, depending on size of the adjacent waterbody); continued subsidence then creates accommodation space on the bay-bottom and *Shelly Bay-bottom Mud* is deposited above the hiatal surface on the outer profile, maintaining the profile (Fig. 5-C, D).

Average ^{210}Pb and ^{137}Cs accumulation rates in the *Shelly Bay-bottom Mud* are on the order of $0.48 \pm 0.16\ \mathrm{cm\,yr^{-1}}$ and $0.59 \pm 0.50\ \mathrm{cm\,yr^{-1}}$ in Barataria Bay and Breton Sound, respectively. These rates may give a general indication of decadally averaged RSLR rates in these areas. Interestingly, a comparison of the thickness of the *Shelly Bay-bottom Mud* and the relative age since retreat of the marsh surface from that location, estimated using retreat rates from wetland loss maps and distance from the present marsh edge, suggests *Shelly Bay-bottom Mud* deposition begins ~50 years after initial marsh shoreline retreat (Fig. 6). Thickness of the *Shelly Bay-bottom Mud* increases with distance from the shoreline, which approximately corresponds to the age since erosion ceased. Thickness also reaches a threshold with distance, presumably as the distance from the primary source of material (the marsh edge) increases.

The DNWR sites in the active Balize delta are a distinct subset of this shoreline evolution model because of the active deposition that dominates this area. This area is susceptible to both rapid compactional subsidence and ongoing Mississippi River sediment input. DNWR sites facing the Gulf of Mexico show a broader, shallow offshore elevation profile despite direct exposure to ocean wave attack. Typically, prograding delta lobes possess a convex profile created by offshore progradation (Bird, 2000). Active deposition from the Mississippi River may form a shallow convex

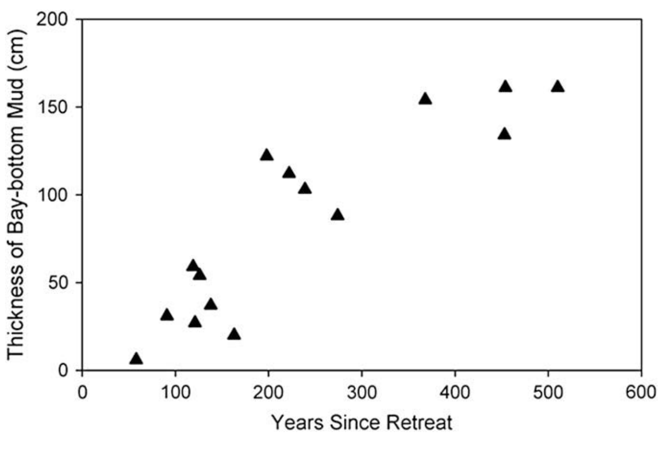

Fig. 6. Thickness of *Shelly Bay-bottom Mud* facies in bay or pond environment versus the time when the marsh shoreline retreated from that location.

profile in which large waves are buffered at the outer edge of the platform where water depths increase rapidly to open shelf depths, and smaller waves translating across the nearshore platform form the shallow concave profile closer to the marsh edge. With lateral retreat of the marsh surface (as caused by Hurricane Katrina in 2005; Barras, 2006), sediment supply from the Mississippi River results in deposition of *Interbedded Sand and Mud* in this delta-front setting, rather than the *Shelly Bay-bottom Mud* found in the more protected, Barataria Bay and Breton Sound sites. DNWR sites in more protected inner ponds, such as DNWR Site 2, are in the early stages of the conceptual model (stage A of Fig. 5) where RSLR is causing submergence of the marsh surface. Unlike *Spartina*, maidencane is able to continue colonization of the inundated pond until a threshold depth is reached (50–100 cm according to David, 1999). Since the ponds are so small in size (~1 km^2), wave action is minimal. Instead, patches of *Panicum* that deteriorate are flushed from the ponds from high river discharge (Kosters, 1989) or tidal and storm surge scour. Rapid RSLR creates accommodation space both on the marsh "surface", now subaqueous, and the adjacent ponds enable a *Massive Mud* deposition because the coarse river-derived supply has bypassed the area.

5.4. Comparison to other eroding marsh shorefaces

In Rehoboth Bay, Delaware, Chrzastowski (1986) and Schwimmer and Pizzuto (2000) describe a similar process to southeast Louisiana marshes where wave erosion of the transgressing marsh shoreline removes a portion of organic-rich sediment and peat (50 cm–1 m thick) from former subaerial marsh, creating an erosional surface overlain with ~50 cm to >1 m lagoonal mud deposits that thicken away from the shoreline. In addition, Tully (2004) found that peat (~1.6 m thick) eroded from marsh shorelines in Pamlico Sound, North Carolina, is a significant source of organic-rich mud deposited in the estuary. This process of peat incision with marsh shoreline retreat and subsequent deposition of eroded material into adjacent water bodies is therefore not unique to Louisiana and our conceptual model may have application in other locations. The magnitude of vertical incision is likely controlled by the rates of RSLR and the wave power affecting the marsh shoreline. Higher RSLR more rapidly deepens the water bodies and affects the wave power translated to the marsh surface. A rapid rate of RSLR is observed in Louisiana (locally as high as 1–2 cm yr^{-1}; Penland and Ramsey, 1990; Shinkle and Dokka, 2004; Törnqvist and Gonzales, 2006) compared to Delaware and North Carolina on the Atlantic Coast (~0.3 cm yr^{-1}; Schwimmer, 2001), however the wave power in Pamlico Sound is presumably larger given the larger fetch of the waterbody.

5.5. Sediment yields to Barataria Bay and Breton Sound

Utilizing the shore-normal elevation profiles measured for each of the study grids (Fig. 2), the volume of sediment yield with retreat of the marsh shoreline can be calculated. According to Sorensen (2006), the volume (V) of sediment (organic + inorganic) that is eroded in a retreating profile can be determined by the equation:

$$V = h\,(\mathrm{d}x)\,(\mathrm{d}y) \tag{2}$$

where dy is horizontal/lateral displacement of the profile, h is height where processes are no longer erosional, and dx is shoreline length. Average shoreline retreat rates for the study grids (dy) were determined using 1932–1990 wetland loss maps (Penland et al., 2000). The annual sediment yield from profile translation along 1 m of shoreline is listed for each of the study grids in Table 4 and assumes no subsidence. Values range from 1.02 to 2.35 m^3 per m of shoreline length per year. RSLR, however, decreases the elevation of the profile and reduces sediment loss by erosion. Taking this into consideration, the actual sediment yield can be calculated by subtracting out the proportion of sediment that would be sequestered from erosion each year by RSLR, and also taking into consideration the amount of sediment accumulated each year on the marsh surface (Table 4). With present uncertainties about subsidence rates in the region only first-order estimates of RSLR are possible. RSLR rates are taken from Penland and Ramsey (1990) for each basin, and accumulation rates from this study are used. Not surprisingly, the sites with the highest sediment yield (LBB 1 and UBB 1, Table 4) are also the most exposed to wave attack and display the deepest offshore elevation profiles. The sediment yields estimated from the translation of the equilibrium profile (from Eq. (1) varied on average ±5% from that calculated from the measured elevation profiles (Table 4), therefore the profile of equilibrium can

Table 4

Top-Estimated sediment yields in study areas calculated from transect data and equilibrium profile. *Bottom*-Sediment yields in Barataria Bay and Breton Sound from 1932–1990 using equilibrium profile model. See text for explanation

Location	Shoreline retreat rate[a] (m yr^{-1})	Maximum depth of profile (m)	RSLR rate[b] (m yr^{-1})	Annual sediment yield (m^3 per m of shoreline)	Equilibrium profile annual sediment yield (m^3 per m of shoreline)
LBB 1	1.59	1.45	0.0111	2.32	2.39
LBB 2.1	1.05	1.42	0.0111	1.49	1.57
LBB 2.2	0.83	1.50	0.0111	1.24[d]	1.24[d]
UBB 1	1.28	1.84	0.0111	2.35	1.92
UBB 2	0.84	1.52	0.0111	1.27	1.26
UBB 3	1.02	N/A[c]	0.0111	N/A[c]	N/A[c]
IBS 1	0.76	N/A[c]	0.0104	N/A[c]	N/A[c]
IBS 2	0.74	1.72	0.0104	1.27[d]	1.11[d]
IBS 3	0.66	1.55	0.0104	1.02[d]	0.99[d]
IBS 4	0	1.12	0.0104	0.00	0.00
IBS 5	0.76	1.60	0.0104	1.22	1.15

Basin	1932–1990 Land loss area (m^2)	1932–1990 Sediment yield (m^3)	Organic material yield (MT)	Inorganic material yield (MT)	Annual organic material yield (MT)	Annual in organic material yield (MT)
Barataria Bay	58.3×10^5	80.2×10^5	4.2×10^5	24.7×10^5	7.3×10^4	42.5×10^4
Breton Sound	62.2×10^5	88.9×10^5	5.3×10^5	25.9×10^5	9.1×10^4	44.7×10^4

[a] Shoreline retreat rates determined from wetland loss maps by Penland et al. (2000).

[b] RSLR rate from Penland and Ramsey (1990).

[c] Sites UBB 3 and IBS 1 were omitted because they occupied a marsh channel or bayou.

[d] Marsh accumulation rates were not calculated for these sites, so they were not included in corrected annual sediment yields.

be very useful in estimating sediment yield in areas experiencing similar lateral retreat of the marsh surface.

On average, marsh retreat annually in Barataria Bay and Breton Sound yields $\sim 1.7\ m^3$ and $\sim 1.2\ m^3$ of sediment per m of shoreline length, respectively. These volumes of annual sediment yield from marsh retreat are comparable to those determined by Tully (2004) for eroding marshes in Pamlico Sound, North Carolina. In that study, ~ 1.6 m of peat was eroded at $1.32\ m\,yr^{-1}$, corresponding to $2.11\ m^3\,yr^{-1}$ per m of shoreline length. It was determined that $2.16 \times 10^6\ m^3\,yr^{-1}$ is liberated by marsh erosion into Pamlico Sound.

Taking into account porosity and average percent organic content for the marsh cores and specific gravity conversions for organic and inorganic sediment (organic $= 1.14\ g\,cm^{-3}$, inorganic $= 2.61\ g\,cm^{-3}$; Callaway et al., 1997), an estimate of the mass of organic and inorganic sediment yield annually can be calculated for these estuaries per m shoreline length. For Barataria Bay, this corresponds to an annual yield of 0.09 MT (MT = metric ton) of organic material and 0.53 MT of inorganic material per m shoreline. The annual organic and inorganic yields to Breton Sound are slightly less: 0.07 MT of organic material and 0.35 MT of inorganic material per m shoreline.

The total yield of organic and inorganic sediments to the Barataria and Breton Sound basins from 1932 to 1990 can be estimated using the equilibrium profile and wetland loss maps of Penland et al. (2000). This approach includes: 1) multiplying the area of bay-fronting shoreline loss by the depth of incision of the equilibrium profile (1.5 m) to obtain a volume from profile translation, 2) subtracting the volume of sediment that would be sequestered from RSLR in this time period (RSLR rates from Penland and Ramsey (1990), 3) adding the volume of sediment which would have accumulated on the marsh surface during this time period, and 4) using porosity, organic content, and specific gravity measurements as explained previously to derive the organic and mineral mass fraction yielded (Table 4). Using a POC/POM conversion of 0.5 (Mitsch and Gosselink, 2000), these values equal an annual POC yield of approximately 3.7×10^4 MT for Barataria Bay and 4.6×10^4 MT for Breton Sound. By comparison, estimates of annual POC flux from the Mississippi River into the Gulf of Mexico are 9.3×10^5 MT (Bianchi et al., 2007). Caution must be exercised with these results because assuming a constant accumulation rate at the core location is an oversimplification. Numerous studies indicate that local variations in marsh accretion rates are associated with proximity to tidal streams, bayous, or other water bodies. Marshes proximal to the water bodies receive more sediment and have higher accretion rates than those farther inland (Delaune et al., 1978; Hatton et al., 1983; Baumann et al., 1984; Childers and Day, 1990). In addition, we assumed a constant lateral retreat rate of the marsh shoreline, but erosion and lateral retreat of the marsh surface may be episodic, driven by inter-annual winter storm patterns and individual cyclonic storms. Regardless, this study highlights a largely ignored but potentially significant labile carbon source to coastal areas.

5.6. *Implications*

Eroding marshes in Louisiana are ideal for studying marsh shoreline morphology with sea-level rise, and may serve as a proxy for other marshes in the face of anticipated accelerated sea-level rise (Church and White, 2006; Jevrejeva et al., 2008). Therefore, our conceptual model may have application to predict marsh shoreface evolution on a global scale. Of regional importance, these estimates of annual sediment yields in Barataria Bay and Breton Sound from marsh shoreface erosion may have a profound effect locally: this sediment is a source of recycled material for marsh or bay-bottom accretion that counters submergence driven by RSLR (Hatton et al., 1983; Baumann et al., 1984; Gagliano and Wicker, 1989; Reed, 1989; Turner et al., 2006). Conversely, continued erosion of submerged marsh platforms is an unrecognized source of elevation loss in coastal Louisiana, requiring additional sediment volume in future marsh creation efforts. Furthermore, the increase in tidal prisms from deterioration of bay-fronting barrier systems can be expected to enhance wave attack on marsh shorelines (FitzGerald et al., 2003), and more material can be eroded from the marsh shoreface. It is also likely that the quantities of sediment and organic matter released impacts biogeochemical cycles in the estuaries and, potentially, on the adjacent continental shelf given the large combined meteorological and astronomical tidal flushing of the basins. The organic-rich material potentially fuels local bay and coastal productivity, and contributes to coastal hypoxia on the Louisiana shelf by supplying significant volumes of labile marsh POC to the continental shelf (Kendall and Silva, 2005; Bianchi et al., 2007). Critical future research is needed to determine what proportion of this material is sequestered in these estuaries versus transported offshore, and how this carbon flux impacts global carbon budgets.

6. Conclusions

The results of the present study indicate the following about marsh edge evolution in southeastern Louisiana:

1) Erosional removal of the surficial marsh *Organic-rich Mud and Peat* facies in Barataria Bay, Breton Sound, and the DNWR takes place at the marsh edge and continues subaqueously with shoreline retreat to a depth of $\sim$1–1.5 m. In Barataria Bay and Breton Sound this forms an erosional ravinement surface on top of these former subaerial marsh deposits. In the DNWR the organic lithofacies are thin and poorly developed and the entire facies is removed with lateral retreat of the marsh, or with tidal/riverine flushing.
2) RSLR creates accommodation space in these bay, pond, and Gulf-fronting areas, contributing to the formation of a *Shelly Bay-bottom Mud* facies deposited on top of the eroded subaqueous marsh platform in Barataria Bay and Breton Sound. Sediments from the Mississippi River dominate the subaqueous deposits in the DNWR.
3) Elevation profiles indicate that shore-normal slopes approximate an exponential profile of equilibrium in both Barataria Bay and Breton Sound. Profiles are concave in shape, with a marsh scarp ($\sim$50 cm) at the edge of the marsh platform, a steep slope to $\sim$50 m offshore, and then decreasing slopes that are asymptotic with the bay-bottom at $\sim$1.5 m water depth (>300 m offshore).
4) A conceptual model similar to those presented for sandy shorefaces describes the geomorphology of eroding marsh edges in southeastern Louisiana. This model takes into account the lateral and vertical translation of an equilibrium profile created by RSLR and wave erosion, and the onlap of estuarine sediments (*Shelly Bay-bottom Mud*) within accommodation space created in the open-water environments.
5) Translation of the profile of equilibrium has been used to estimate erosional sediment yields to estuarine areas of Barataria Bay and Breton Sound. It was determined that $1.7\ m^3\,yr^{-1}$ (0.53 MT of inorganic sediment and 0.09 MT of organic matter) is currently provided per m shoreline length in Barataria Bay, and $1.2\ m^3\,yr^{-1}$ (0.35 MT of inorganic sediment and 0.07 MT of organic matter) is yielded per m shoreline length in Breton Sound. From 1932 to 1990, an annual POC yield of approximately 3.7×10^4 MT and 4.6×10^4 MT was calculated for Barataria Bay and Breton Sound, respectively.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.ecss.2008.09.004.

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