Organic Geochemical Proxies as Indicators of Paleoenvironmental Conditions and Source Sediment Provenance in the Chenier Plain, Vermilion and Cameron Parishes, Louisiana, USA

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Organic Geochemical Proxies as Indicators of Paleoenvironmental Conditions and Source Sediment Provenance in the Chenier Plain of Vermilion and Cameron Parishes, Louisiana, USA

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ABSTRACT

Estuarine environments along Louisiana's coast provide sheltered depositional environments where sediment accumulates at or near relative mean sea level rise in a consistent horizontally-layered sequence. This depositional environment provides a sequential record of sediment and environmental changes. Geochemical and organic geochemical proxies are increasingly being used to study Holocene sedimentation to reconstruct relative sea level rise and environmental changes (Lamb et al., 2006). The carbon isotope composition of organic matter ($\delta^{13}C$) and the ratio of total organic carbon to total nitrogen (C/N) indicate source, providing a tracer of the carbon pathway and storage in estuarine environments. Carbon isotope ratios of preserved organic matter have been proven as useful environmental proxies; thus, changes can be used to interpret an estuary's position relative to sea level and to paleoriver discharge (Lamb et al., 2006). Additionally, using ^{137}Cs, as an indicator of accretion rate, aids in constraining the data to a timeline. Cesium-137 is a useful timestamp and has been used extensively in the Northern Gulf of Mexico and coastal Louisiana as an indicator of accretion rate (Delaune et al., 1989). This thesis applies these geochemical proxies to a sequentially sampled one-meter-long soil core from the Chenier Plain in Southwest Louisiana. The paleo-environmental record of accretion rate and organic carbon sources to the Chenier Plain estuarine environment are compared to known environmental changes in sea level, plant community, and hydrology over the past century.

The resulting data indicates that human influences on hydrology in the Chenier Plain have served to alter organic carbon sources, namely increasing marine influence to previously freshwater habitats and restricting freshwater sheet flow from the Mermentau River basin. These changes and new hydrologic projects that aim to restore historic conditions have increased intermediate marsh habitat by facilitating increased movement of fresh and marine water throughout the Chenier Plain.

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1. INTRODUCTION

The southwest coast of Louisiana contains several relict beach ridges, stranded inland by coastal accretion. These land forms, called cheniers, separate and protect wetlands that make up the Chenier Plain. The estuarine environments of the Chenier Plain are sheltered from turbulent gulf waters preventing redistribution and mixing of sediments, but also remain connected to the Gulf of Mexico tidally. Normal tide movement supplies the estuaries with water rich in sediment from the Atchafalaya and Mississippi deltas. Rising sea levels provide vertical growth pressure to vegetation, stabilizing deposited sediments, creating a positive feedback loop for preserving thick sequences of Holocene sediments. This sedimentary organic matter offers a record of past environment and sea-level changes because production, transport, and preservation are affected by environmental changes. The rate of sedimentation or vertical accretion occurs at or near relative mean sea-level rise. In Louisiana, this is mostly affected by regional sediment compaction and settling of Mississippi river distributary sedimentary deposits into the Gulf of Mexico basin. Particularly, the combined effects of compaction and consolidation of Holocene and Pleistocene sediments, fluid removal, faulting, and biotic root zone processes combined with eustatic sea level rise has contributed to relative sea level rise (Penland et al., 1989). In the Chenier Plain, the accretion rate is estimated to be 0.4 to 0.8 cm yr^{-1} (Delaune et al., 1989; Shen 1994).

Over the past century changes in vegetation and hydrology have altered the Chenier Plain's environment. Using late Holocene paleoclimate records from coastal environments is useful in understanding long-term variability of sea level and vegetation changes (Das et al., 2013).

As coastal sediment deposits form a significant proportion of global carbon storage (Bauer and Druffel, 1998), the response of these sediments to sea level rise is of great interest. The carbon isotope ($\delta^{13}C$) value of organic matter was first used in 1967 by Emery et al. to distinguish salt marsh and peat marsh sediments, but reasons for their variability were not known. As these relationships have been further studied, it was discovered that there are distinct physiological differences in the way different groups of plants (C_3 plants, C_4 plants, and algae) assimilate carbon into their tissues. These differences in CO_2 uptake and processing create changes in the ratio of carbon isotopes assimilated from the atmosphere. This results in a predictable differentiation of atmospheric CO_2 and leads to identification of organic material source by its $\delta^{13}C$ value. Combining carbon isotope values with organic carbon to total nitrogen ratios (C/N) can be useful when studying environments that receive organic carbon from terrestrial and marine sources (Meyers 1994). Algae do not contain lignocellulose, and therefore have a much lower C/N ratio than terrestrial land plants

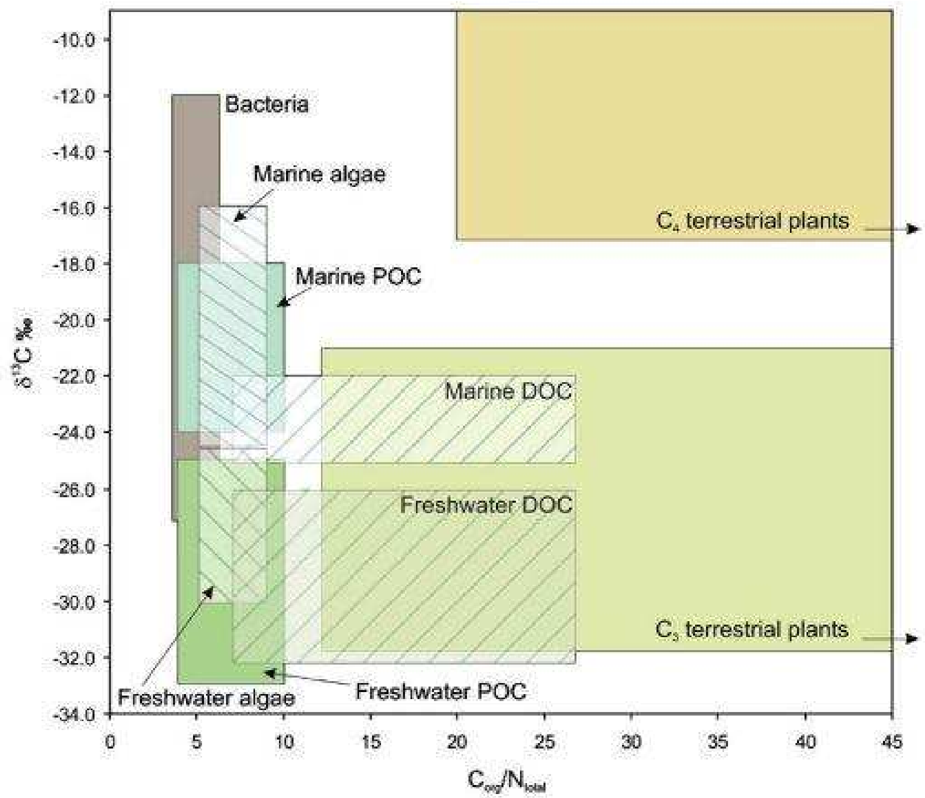

Figure 1. "Typical δ^{13}C and C/N ranges for organic inputs to coastal environments (reproduced from Lamb et al, 2006, data compiled from Bordovskiy, 1965a; Haines 1976; Deines, 1980; Sherr, 1982; Schidlowski et al, 1983; Meyers, 1994; Peterson et al,1994; Schleser, 1995; Tyson, 1995; Middleburg and Nieuwenhuize, 1998; Chivas et al, 2001; Raymond and Bauer, 2001; Cloern et al, 2002; Goni et al, 2003; and references therein)." (Lamb et al., 2006)

Estuarine salt marshes receive allochthonous fluvial and marine-derived minerogenic sediment and particulate organic matter (POM) and dissolved organic matter (DOM). Autochthonous organic matter comes from salt marsh plants and other biota. Use of δ^{13}C values in coastal sediment provenance studies has become common (Das et al., 2013, Chmura and Aharon, 1995). Das et al. 2013 showed that significant variations in ^{13}C, C%, N% and C/N with depth reflected changes in estuarine environments. Investigations into the source of carbon can reveal whether the source was terrestrial or marine and what effect the environments it migrated through had on its final composition. Analysis of carbon and nitrogen isotopes creates an organic geochemical fossil record that provides an accurate paleo-environmental record. In this study, three sediment cores from Rockefeller Refuge in southwest Louisiana were analyzed for their organic geochemical signatures including $\delta^{13}C$ value, C%, N%, and C/N ratios. Cesium-137 was also analyzed to establish an average sedimentation rate for each core, creating a chronological framework for interpretation of the geochemical data. The cores were taken immediately after Hurricane Rita in locations cored five years previous to evaluate the effect of storm surge on sediment accretion rates. The data were used to reconstruct environmental changes in the Rockefeller refuge over the last century to study changes in geomorphological processes affecting the Chenier Plain.

2. BACKGROUND AND REGIONAL SETTING

Ecologic Importance

Ecologically, the Louisiana Chenier Plain encompasses approximately 3,085 km^2 of wetland systems that serve as an important stop for birds crossing the Gulf of Mexico while migrating through the Mississippi flyway (Chabreck and Joanen, 1989). The vast productive marshes are part of estuaries for many marine organisms and support the overwintering and raising of many migratory bird species (Chabreck et al., 1989). Rockefeller refuge is home to a large American alligator research program, as well as many other notable species endemic to the Northern Gulf coast (e.g. Lance, 2003; Greenberg and Maldanado, 2006). The area has been historically noted as extremely productive in the way of wild game, especially of the choicest birds and fish (Davidson, 1884). Activities of the region revolve around the harvest of the season. Wildlife provides the main economic resources tying the ecology of the region to its inhabitants. And wildlife is directly tied to habitat. In the winter months, ducks, oysters, and furs are harvested and processed while cattle are moved from the marsh inland for the warm season. In the spring and summer months, fish, crab, crawfish, shrimp, and alligator are harvested and cattle are moved into the marsh to graze during the cool season.

Geologic History

The Northern Gulf of Mexico's waters contain sediments from the Mississippi River and Atchafalaya River distributary systems. The Gulf of Mexico's counterclockwise circulation brings the suspended sediment westward across Louisiana's coast from the mouth of the Mississippi and Atchafalaya. The Chenier Plain formed and began to stabilize 3,000 to 4,000 years ago as global sea level rose to its current level (Gosselink et al., 1979). The geomorphology of the Chenier Plain is therefore better understood if the area is characterized by its surrounding environments. The Chenier Plain is positioned on the coast to the south of the coastal prairie region, expanding west from Vermilion Bay to Galveston Bay in Texas. The very slightly undulating surface of the prairie is a Pleistocene terrace that forms the first upland environment north of the Chenier Plain. There is a disconformity between the Pleistocene terrace and the overlying sedimentation of the Chenier Plain. The Pleistocene terrace forms an abrupt edge on the northern extent transitioning into vast fresh marshes southward. When the Mississippi River held a westerly course during the Teche delta complex phase 3500-2800 yr BP, the Chenier Plain prograded as a series of vast mudflats from riverine sediment flowing out of the Atchafalaya and Mississippi River into the Gulf of Mexico. As delta progradation processes culminated and the river shifted to a slightly more eastward course during the same period (3500-2800 yr BP), erosive wave action reworked the sediment into high beach ridges. As the delta shifted back westward within the Teche delta complex (3500-2800 yr BP) further mudflat progradation stranded them inland, allowing the former beach ridges to become colonized by live oak trees. Around 2800 yr BP, the Mississippi began favoring its most easterly course through the St. Bernard delta complex, allowing erosive forces to once again dominate and rework sediment into beach ridges. When the Mississippi River's course switched west again ~1000 years BP to the Lafourche delta lobe, progradational forces dominated and the Chenier Plain transgressed seaward. Changes within the Lafourche delta lobe and temporary distribution through the Plaquemine delta lobe created the majority of the Chenier's geomorphology (e.g. Penland and Suter, 1989; McBride et al., 2006). By 300 years BP the Lafourche delta lobe was completely inactive, the Mississippi River's course switching to the Plaquemine delta, allowing erosive forces to once again dominate the Chenier Plain coastline. Through minor

Mississippi distributaries like the Atchafalaya, sediment has accreted in restricted areas on the easternmost and westernmost sides of the Chenier plain. Mulberry Island, located at the easternmost extent, is currently accreting from Atchafalaya sediments. The oak grove ridges, or "*chenieres*" (French), as first named by the Acadians (the first European inhabitants of the region), are the dominant feature of this ridge and swale topography, now called the Chenier Plain. Within the belt of fresh marshes that runs parallel to the coast south of the coastal prairie, are drowned Pleistocene entrenched river valleys, flooded ~5,000 years ago (Fisk, 1944). Longshore transport of sediment from the Mississippi constricted their southern ends to the extent that only small tidal passes (1-2.7 m deep) remained prior to the 1890's (Gammill et al., 2002). The lakes they form, Lake Calcasieu, White lake, Grand Lake, and Sabine Lake, are expansive inland fresh and brackish estuaries. South of the prairie, the cheniers form the only topographic relief besides the modern beach. Within the fresh marshes, the cheniers form long islands, parallel to the coast, becoming more frequent and apparent towards the south. The cheniers transition sequentially in age southward, where younger cheniers are less weathered and subsided. The oldest cheniers, farthest north, are confined laterally and form ecological "islands" within the fresh marsh system. Ridge complexes to the south, including Pecan Island and Grand Chenier, are more numerous and higher in elevation. They form the transition from fresh marshes on their north side to intermediate and brackish marshes on the south side. The intermediate and brackish marshes transition to saline near the modern coastline, and form the southern extant of the chenier plain. The ancient beach ridges and low marshes, that are in-between the relict beach ridges, form a complex system of estuaries. This ridge and swale topography is generally parallel to the coast, and creates a diverse complex of estuaries with varying degrees of salinity and hydrologic connectivity.

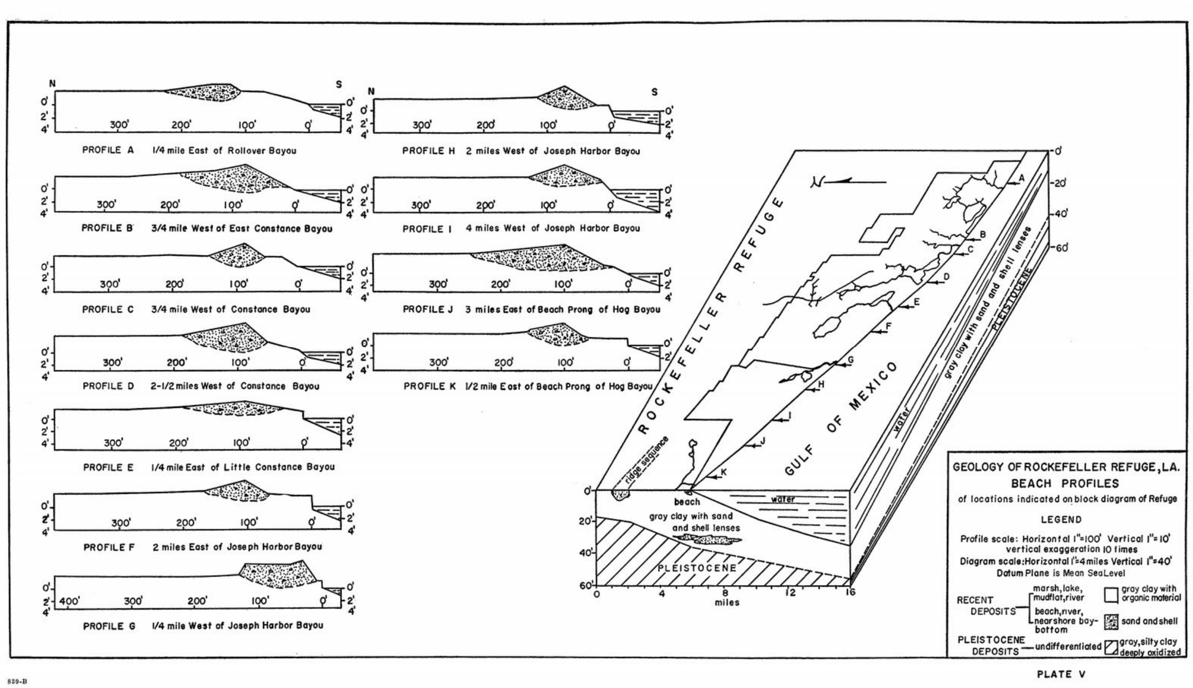

Figure 2. The Geology of Rockefeller Refuge, illustrating the geomorphology of the coastal ridge system. Reproduced from Nichols, 1959.

Between the modern beach and the next major ridge system, oligohaline wiregrass and mesohaline mixture marshes collect sediments from the Atchafalaya and Mississippi during normal tidal movement. High-energy winter storms and occasional tropical disturbances provide the main sediment reworking and depositional events besides normal tide movement. Winter storms at a frequency of 20-30 per year rework sediment deposited on the wide continental shelf, depositing most of the Chenier Plain's mineral sediment (Roberts et al., 1989; Reed, 1989; Cahoon et al., 1995). As the sediment supplied to the Gulf of Mexico by the Mississippi diminishes, the coast transits into barrier islands and bays at Galveston Bay, Texas. Rockefeller Refuge is located on the southern coast of the Mermentau River basin, in the Chenier sub-basin and lies in the tidal zone between the Grand Chenier - Pecan Island ridge and the current shoreline (Fig. 3). The dominant allochtonous sediment sources to the refuge are the White Lake estuary to the north and the Atchafalaya River delta to the east, while the dominant autochtonous organic matter source is decomposing native vegetation.

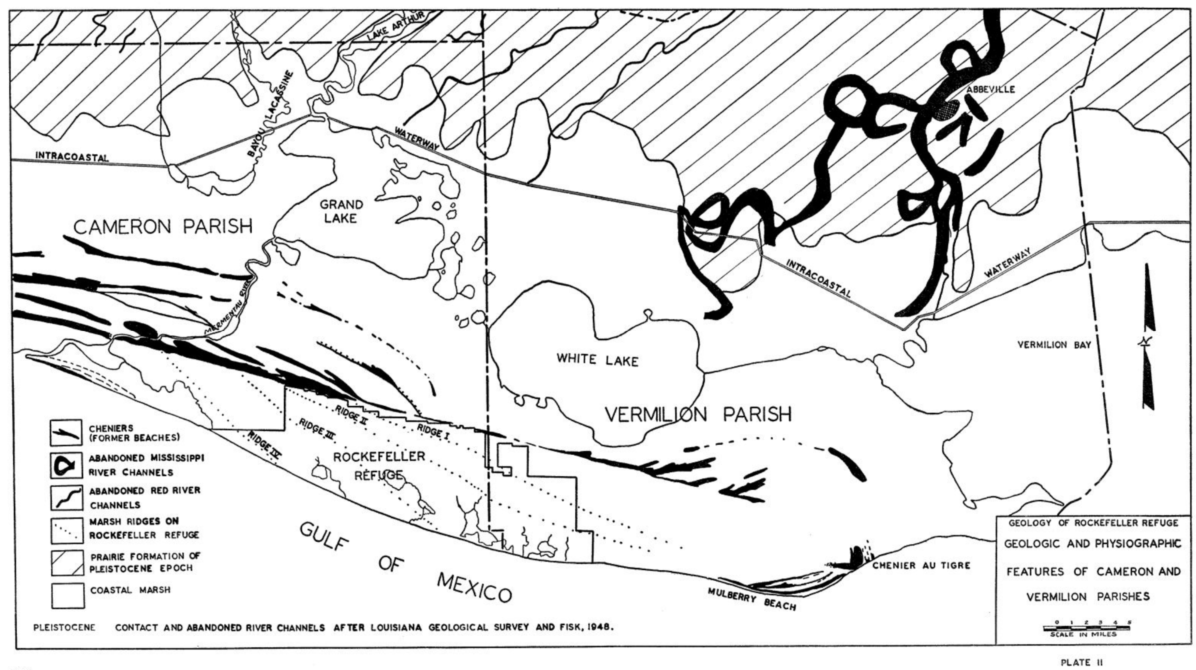

Figure 3. Reproduced from Nichols, 1959. Geology and physiographic features of Cameron and Vermilion Parishes showing the Pleistocene prairie terrace shaded with diagonal lines, abandoned Mississippi River channels (thick black meanders) and the cheniers in black running east-west near the coast.

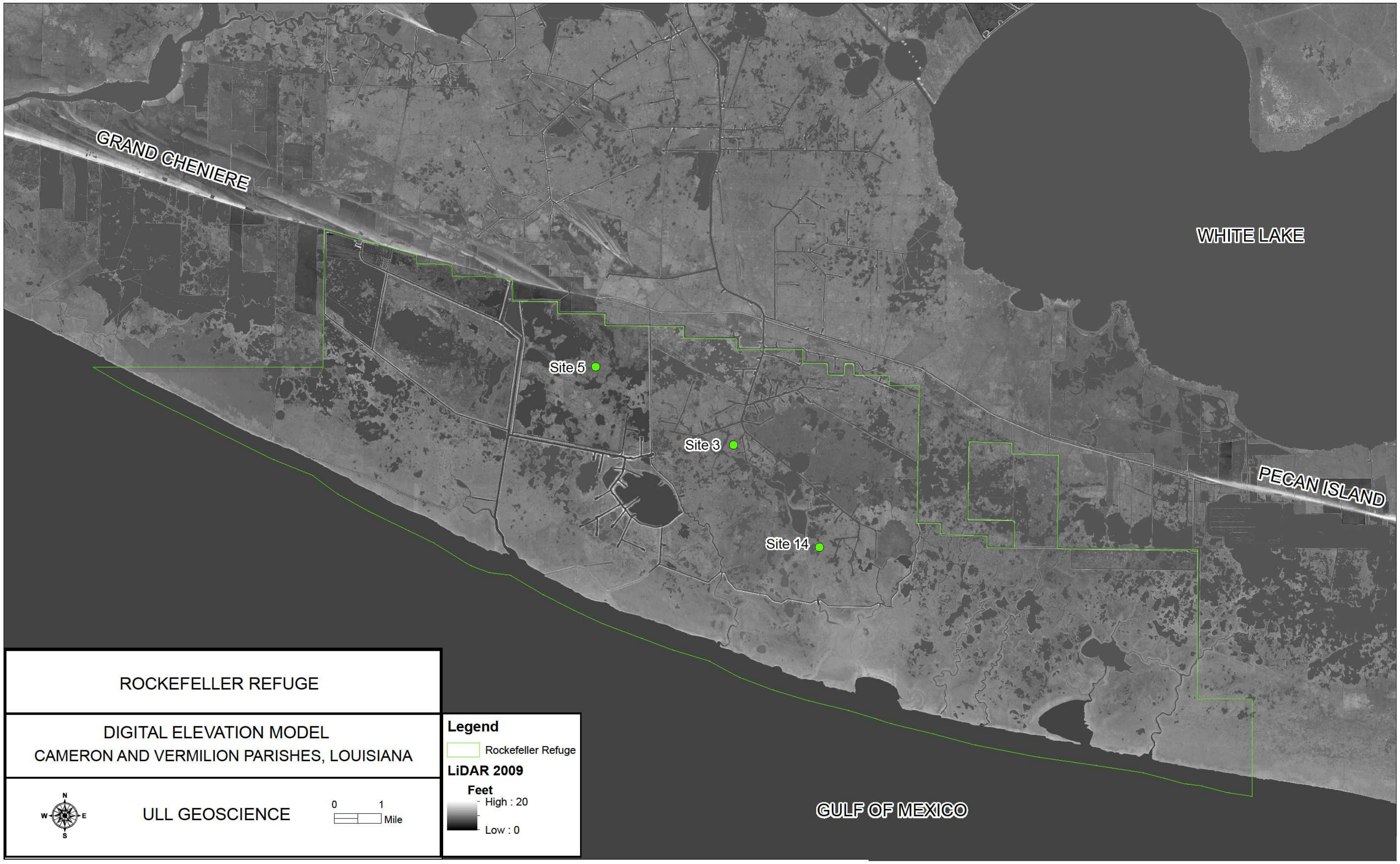

Figure 4. Rockefeller Refuge outlined in green and study sites labeled with green dot. The base map is a digital elevation map created using LiDAR, with black being the lowest value and white, the highest. (Base map layer created by Louisiana Oil Spill Coordinators Office in 2009, hosted by LSU Center for Geoinformatics.)

Marsh elevation and the coastal marsh ecosystem is a function of hydrology, plant productivity, and sediment dynamics. "In salt marsh highly organic soils develop where less tidal action occurs; in tidal areas particulate organic carbon (POC) is the dominate source."(Lamb et al., 2006). A conceptual model proposed by Cahoon et al., (1999) shows the principal inputs and feedbacks in the coastal marsh system (Figure 4). These dynamic processes are the causes of change in sediment sources, where organic rich soils accumulate in fresher, mineral sediment restricted areas and mineral dominated soils accumulate in areas where tidal action provides mineral sediment input. In tidal waters, sediment and nutrients are imported into the marsh and contribute to above and below ground productivity (Cahoon et al., 1999).

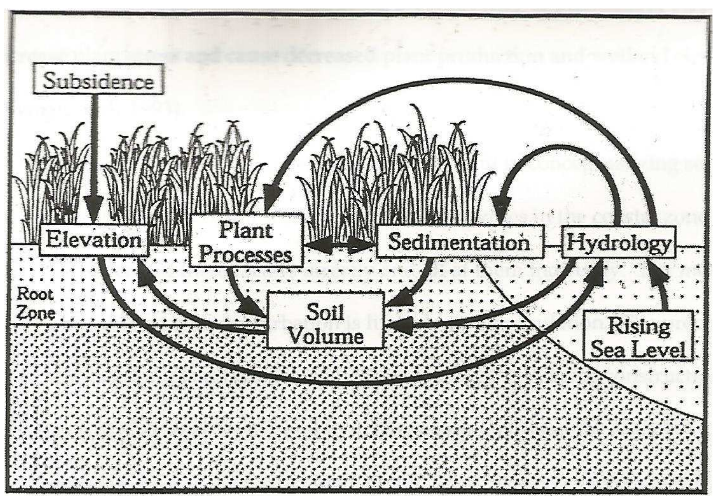

Figure 5. Conceptual model of factors that contribute to wetland elevation. From Cahoon et al., 1999.

Compaction rather than degradation was found to be the major factor in consolidation of sediments below 4m in depth (Turner et al., 2006). Marsh responds to the dynamic process of tidal import and deposition of materials onto the marsh surface and the response of the plant community to that inundation and deposition. As marsh elevation decreases, the extent of tidal inundation increases and more material is deposited onto the marsh. The increased frequency of inundation may stimulate plants to produce more biomass, thereby increasing elevation and reducing the frequency of inundation, or, it may increase plant stress and cause decreased plant production and wetland elevation (Nyman et al., 1993). This model is a complex interaction of dynamic feedback loops of the factors that affect coastal wetlands.

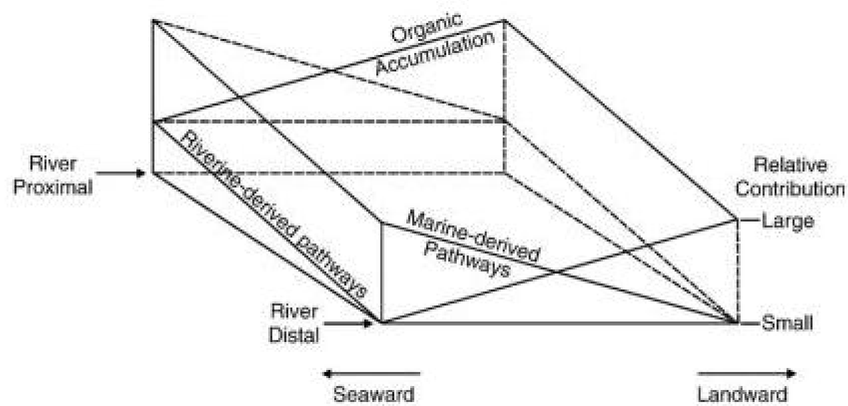

Figure 6. Figure reproduced from Lutenauer et al., 1995 depicting the relative contributions and provenance of sediment to an estuarine marsh based upon relative proximity to different sediment sources. This simplified figure shows the dynamic nature of the organic carbon signal in estuarine systems as a mixture of all available sources, not simply one or the other. Autochtonous organic accumulation dominates at landward locations and transitions to allochtonous marine dominated at coastal locations. While proximity to the Atchafalaya and Mississippi River dictate the riverine influence.

Hurricane History

Reworking and deposition of Atchafalaya and Mississippi River sediments during winter storms and hurricanes are critical processes towards maintaining land elevation (e. g. Cahoon, 2002; Foret, 2001; Turner et al., 2006, Turner and Tweel, 2012). Several major hurricanes have shaped the Chenier Plain in recent history. As hurricanes approach the wide continental shelf in the northwest Gulf of Mexico, winds push water into a storm surge that is greatest in the northeast quadrant of the storm. Storm category, angle of approach, and speed, and sediment availability affects the amount of sediment deposition that occurs on the marsh (Cahoon et al., 1995; Nyman et al., 1995). The last major hurricane to significantly impact and flood the Chenier Plain with storm surge represented in the data was Hurricane Rita in 2005. Hurricane Rita's storm surge was recorded at a maximum of 17 feet over the Chenier Plain. The storm's eye hit in Louisiana near the Texas border blowing the highest surge, on the northeast side, over Grand Chenier and Rockefeller refuge. In the cores used for this study, the storm surge sediment layer was found to be 6 cm thick. Hurricane Lili made landfall near Intracoastal City on the eastern edge of the Louisiana Chenier Plain in 2002, but it did not deposit much sediment due to the storm surges main location to the northeast of the eye, putting the surge over Vermilion Bay, east of the Chenier Plain (Tweel et al., 2014). On June 25, 1957 Hurricane Audrey struck between Cameron and Sabine pass, near the Texas border with sustained winds of 120 mph and storm surge height of 3.7 m (Morgan et al., 1958). It is evident from NOAA's storm history that a few storms could have affected the Chenier Plain like Hurricane Audrey and Hurricane Rita. The 1900 hurricane that struck Galveston and the 1837 hurricane, Racer's Storm are known to have been category 4 and 5 hurricanes. Tweel and Turner (2012) estimated the inorganic sediment deposited onto Louisiana's coast from Hurricane Rita to be 48 million metric tons. The storm surge recorded by NOAA buoy 42010 was 11.1 m on average for the highest one-third of the waves measured during the buoys sampling period (40 minutes). The maximum wave period during this event increased to 16 seconds (NOAA, 2012). The shear stress produced by such waves is capable of suspending grains at least as coarse as sand (1 mm) at water depths greater than 42 m (Madsen, 1994; Miller et al., 1977). This implies that sediment deposited on the continental shelf, which transitions to depths greater than 43 m at its edge far offshore, is available for transport during such storm surge events. Hurricanes deposit 5.6 million metric tons of inorganic sediment on Louisiana's coast yearly on average (Tweel and Turner, 2014), which equates to 3.8% of the modern Mississippi Rivers annual sediment load (Meade and Moody, 2010) and 3.2% of the estimated pre-disturbance load (Tweel and Turner, 2012). These measurements of storm surge sedimentation of redistributed Mississippi River sediments indicate an important geomorphological land building process previously understudied. Hydrology has been anthropogenically altered with canals and levees altering sheet flow, preventing historically active natural processes of land growth. Therefore storm surge redistribution of Mississippi River sediment from the continental shelf onto the coast is an integral process of Louisiana wetland growth.

Hydrologic History

In terms of hydrology, Rockefeller Refuge lies in the center of the Chenier sub-basin, in the Mermentau River basin (Gosselink et al., 1979). White Lake and Grand Lake once acted as shallow, low salinity estuaries before the U.S. Army Corp of Engineers constructed locks and water control structures to control salinity for agriculture (Gunter and Shell 1958; Morton, 1973). The lakes are 2 m deep on average and received only minor marine influence from a few narrow shallow tidal passages, due to constant longshore transport of sediment on the coast filling in these channels. Previous to alterations made by humans, natural drainage occurred North to South through the Mermentau River, Freshwater Bayou, Bayou Lacassine, Rollover Bayou, and sheet flow between Pecan Island and Grand Chenier (Gammill et al., 2002). Human impacts to the hydrologic regime of the Chenier Plain have been extensive (Gammill et al., 2002).

The 'Hydrologic Investigation of the Louisiana Chenier Plain' (Gammill et al., 2002) found that historical hydrologic landscape changes were the major driver of land loss. Throughout the 19th and 20th centuries land use changes adjusted the historically North-South hydrology to a segmented East-West flow. The Old Intracoastal waterway (dug in 1925) and the New Intracoastal waterway (dug in 1933) completely dissected the Chenier Plain from the northern part of the hydrologic basins by introducing an enormous channel with East-West flow and spoil bank that interrupted and changed overland sheetflow to the region. Deepening of the tidal channels allowed for increased tide action in the lakes changing the salinity regime, thus changing vegetation, contributing to the complete loss of the dominant saw grass (*Cladium jamaicense*) from the region. Shifting vegetation indicated human induced saltwater intrusion was a primary cause for management concern and encouraged later hydrologic changes.

In the early 1960's the hydrology was drastically altered by the completion of the state highway (Hwy. 82) between Pecan Island and Grand Chenier. Highway 82 constructed from Abbeville south to Pecan Island then west to Oak Grove and then Highway 27 North to Lake Charles effectively created a levee complex allowing for the creation of the Grand Lake-White Lake freshwater reservoir system by the U.S. Army Corp of Engineers. Outlets originally created to allow for release of flood waters across the highways were allowed to degrade in preference of deepening and widening navigation channels on which control structures and locks could be built. The water level is controlled within the system for freshwater agriculture use. This system, also disconnected from normal tidal movements, is experiencing differential accretion indicated by sea level rise rates, measured by the

U.S.A.C.E. Within the system, the SLR rate is 0.41 cm $year^{-1}$ compared to 0.67 cm $year^{-1}$ outside the system (Gammill et al., 2002). Therefore, sea level rise rate has been artificially decreased within the Lakes sub-basin, putting the ecosystem at an elevational disadvantage in the face of future sea level rise. Due to the lakes restrictions, freshwater is no longer allowed to sheet flow across the area between Grand Chenier and Pecan Island. Historic drainage from White Lake through Floating Turf Bayou to the south of Pecan Island has also been cut off by levees, effectively separating the Mermentau basin into two sub-basins as described by Gosselink 1979. The freshwater lakes sub-basin lies to the north of Hwy. 82 and the Chenier sub-basin to the south of Hwy. 82. Now the Chenier sub-basin acts as a tidally dominated estuary with little freshwater input. Even though new outlets improving freshwater flow to the region have been increased, the landscape is so altered that the hydrology cannot function as it did before canals and levees dissected the estuary into disconnected lagoons, ponds and oilfield canals.

Native American and Early European History

Native Americans, including the Tchefuncte (700 B.C.-A.D. 250), Troyville (A.D. 400-800), Coles Creek (A.D. 800-1100), and Plaquemine (A.D. 1100-1400), left many mound works across the region from Johnson's Bayou to Pecan Island (Kniffen et al., 1987). The mound works include a false chenier, Chenier du Fond, or Alligator Mound the only known shell effigy of the Gulf coast region. It was historically named Chenier du Faux in full recognition of its man-made origin but otherwise was indistinguishable from a chenier. The mound, one of at least 14 around Grand Lake, was estimated to originally be 400 m long, 120 m wide and 7 m above sea level, comparable to the elevation of Grand Chenier today (Howe et al., 1935). It was shaped into a complete alligator comprised almost entirely of the brackish clam

Rangia cuneate (Howe et al., 1935). By 1935 it was diminished to only 200 m in length and later removed completely by barge to be sold as road or fill material. This event highlights the complete removal of shell ridges and diminutive cheniers that were once common throughout the Chenier Plain. Small 1 to 2 m high shell hash ridges deposited across the coast by storms served as important structures to a region dominated by organic rich sediments.

The region's wildlife brought early settlement from French and Spanish colonization in the mid-18th century with the Acadians exile from British Nova Scotia in 1755 (Brasseaux, 1987). In 1766, a Spanish merchant ship, El Nuevo Constante, ran aground near Little Constance Bayou in Rockefeller Refuge (Pearson, 1981). The Spanish government of Louisiana aided in salvage efforts of the precious metal being transported from the Mexican colonies to Spain. This shipwreck became a landmark on the very flat coast that had not been described until 1785. The surveyor, Jose de Evia, was the first to provide a written description of the Chenier Plain during a journey along the Northern Gulf coast commissioned by the colonial government to survey the newly acquired Louisiana Purchase. His first description was of "Punta Encinal del Tigre" ("live oak grove point of the tiger"), known today as Chenier au Tigre (Gomez, 1998). He described the upland ridges dominated by live oaks as separate sections of shoreline. It was not until 1813 that a more detail description of the Chenier Plain was written by William Darby as he journeyed down the course of the Sabine River. He recognized the complex topography as stranded shorelines, abandoned as others formed by the same means. He noted that many of the cheniers formed islands within the wetland complex of southwest Louisiana, seldom or never being visited by humans as no upland or water routes existed to access them (Darby, 1818). From 1806 to

1821 the land between the Sabine and Calcasieu Rivers was disputed as owned by both the Spanish and the Louisiana government. Without any law, the area became a refuge for bandits, pirates and buccaneers. Even after being claimed by the U.S. the area was not fully civilized by law until after the civil war as the terrain is extremely difficult to traverse. Although considered inhospitable by many Americans, J.O. Davidson noted that a group of individuals, including a minister on his way to preach at another island chenier, were encountered during a trek to see the U.S. government's live oak preserve on Pecan Island in 1887. Although rich in wildlife, the area was long considered a vast wasteland by Americans. Virtually all of the Louisiana Chenier Plain, 1,342,844 acres of public land, was sold by the state of Louisiana to Kansas banker, Jabez B. Watkins, in 1884 (Gomez, 1998). Previous to rice and conventional agriculture, hay production and cattle grazing were the dominant Acadian agronomy practices. Acadian practices in Nova Scotia included building weirs to help distribute sediment and nutrients to the vast coastal hay meadows (Brasseaux, 1987). In Nova Scotia, these practices were used to create new land from which to harvest hay. Watkins brought conventional agriculture to the region, including the use of levees to protect crops from salt water and flooding. Watkins' plan was to turn the entire region into rice production, but ultimately failed because the majority of the region was an estuary that experienced salt pulses, killing any rice planted. With the advent of conventional agriculture, the region's hydrology began its transition to its modern condition. In 1883, Watkins brought engineers from Iowa State University to help plan construction of a large canal and levee complex on the shore of Calcasieu Lake (Gomez, 1998). This marked the beginning of levees being built in every upland area of the Chenier Plain, field by field. Building levees around individual agriculture fields and creating impoundments has been the genesis of much of the region's land loss. Without proper management of the fields, the land will degrade and eventually lose sufficient elevation to maintain vegetation cover. Removing the water from the fields allows aerobic decomposition of the organic matter to occur, and compaction of the soil. Louisiana's coastal wetlands continuously grow vertically and accrete land as subsidence and sea level rise occurs. In estuarine environments levees prevent tidal action from signaling plants to grow vertically through the growth pressure of rising sea level essentially trapping them in the past under conditions present when levees were built, such as a lower sea level. Segmented from the greater dynamic ecosystem the marsh no longer receives accretionary pressures to continue to grow and change with the environment as sea level rises. The fields remain at the elevation corresponding to the sea level at the time when they were impounded. As time progresses the entire surrounding ecosystem continues to accrete vertically through natural processes. During catastrophic events like hurricane storm surges that overcome or break the levees most landowners are not capable of managing the water level of their wetlands. And as a field is suddenly reconnected to the coastal ecosystem during these catastrophic events, entire fields of land can be lost in single floods as water drowns the vegetation of the now relatively lower field. The death of all of the vegetation breaks the cycle of vertical accretion and stabilization by vegetative growth, allowing the area to transition to open water.

Vegetation History

The nearest CRMS site 0608, lists *Phragmites australis* (Cav.) Trin. Ex Steud (Poaceae) as the current dominant vegetation of the areas near the sample sites. A salt tolerant (Vasquez et al., 2005) haplotype of this species was recently discovered in America and has been implicated in the invasion of this species into salt and brackish marshes usually dominated by

Spartina alterniflora and *Spartina patens* (Staltonstall, 2002; Stalstall et al., 2004). The extensive spread of *P. australis* throughout brackish marshes on the Atlantic coast has become a major issue with regard to coastal management and restoration (Able et al., 2003; Lantrhop et al., 2003; Windham and Myerson, 2003). Vasquez et al., (2006) showed that the M haplotype of P. australis has a higher growth rate and greater salt tolerance than native haplotypes, allowing it to become established in *Spartina* marshes. Currently the aggresive strains effect on the regions vegetation has been restricted to areas of human influence, particularly waterfowl hunters, but of its quick rate of infection into select areas, such as Rockefeller Refuge, is an indicator of its virile growth ability in the Louisiana Chenier Plain (Stanton, 2005). Herbicide use in marsh management on the Chenier Plain is becoming more common in preserving wildlife habitat, as *P. australis* does not provide forage and the aggressive cespitose growth habit replaces valuable vegetation (Stanton, 2005). *P. australis* is only distinguishable in the field from the native form by its flowering time and growth habit. And thus, the cryptic nature of its colonization results in it not being recognized until it exhibits invasive traits of overgrowth and habitat quality reduction.

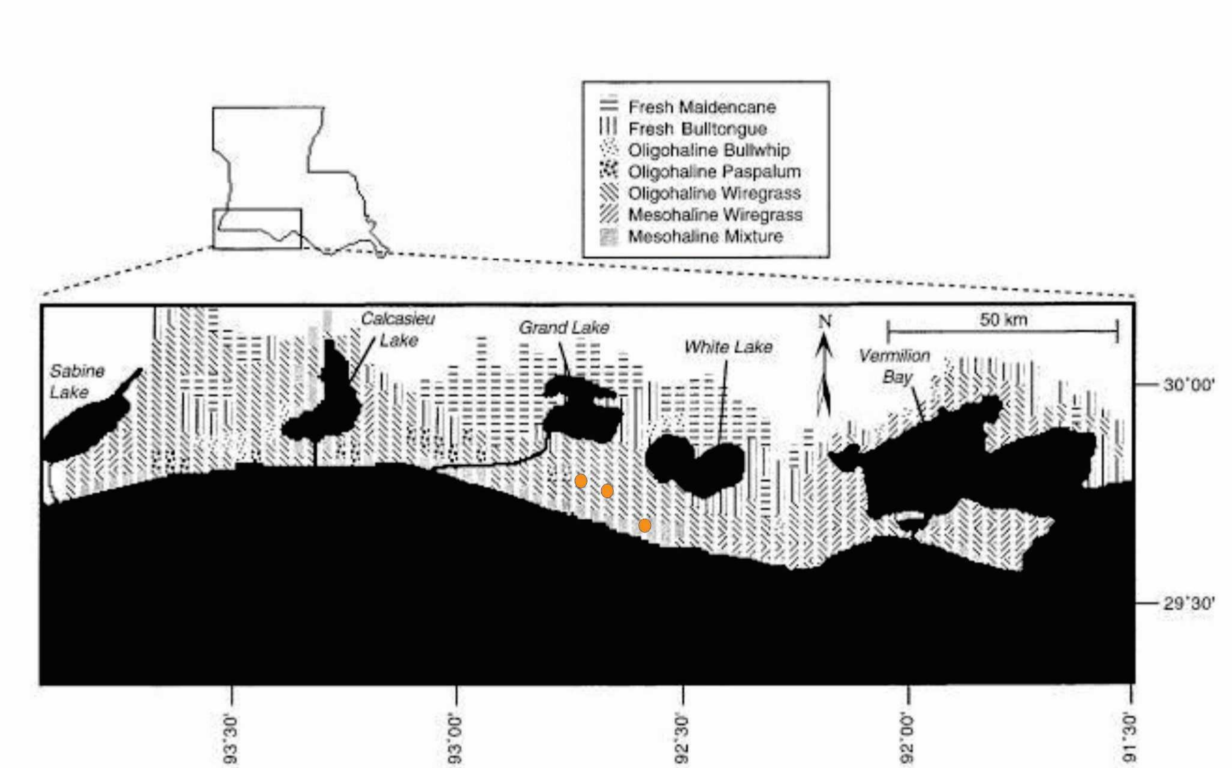

Figure 7. Reproduced from Visser at al., 2002. Based on vegetation habitats surveyed in 1997. Core location sites indicated with orange dots.

Sasser et al. (2013) describe the north-central portion of Rockefeller Refuge as intermediate marsh frequently dominated *by Leptochloa fusca* (C_4), *Panicum virgatum* (C_4), *Phragmites australis* (C_3-C_4 intermediate), or *Schoenoplectus americanus* (C_3). Intermediate marshes in this area are colonized by an oligohaline wiregrass mixture; *Spartina patens* (C_4) as the dominant species, with other species intermixed, including *Sagittaria lancifolia* (C_3), *Schoenoplectus americanus* (C_3), *Phragmites australis* (C_3-C_4 intermediate*), Eleocharis spp.* (mostly C_3, some C_3-C_4 intermediate), and *Cyperus spp.* (mostly C_4, some C_3-C_4 intermediate) (Soros and Bruhl, 2000). Fresh marsh wetlands, located inland from the study site, are frequently dominated by *Panicum hemitomon* (C_4), *Sagittaria lancifolia* (C_3), *Eleocharis baldwinii* (C_3-C_4 intermediate), or *Cladium jamaicense* (C_3). Brackish marshlands to the south of the site are primarily dominated by *Spartina patens* and sometimes by

Spartina cynosuroides, *Spartina spartinae* or *Bulboschoenus robustus* (Sasser et al., 2013). Visser et al. (2000) studied vegetation communities and compared results with Chabreck (1972) and O'Neal (1949) to identify changes in the region. The study showed the area of fresh marsh decreasing drastically with the largest change from 50% to 34% from the early 1940's to 1968. This change has been attributed to the conversion of sawgrass (*Cladium jamaicense*, C_3) marsh to intermediate marsh following the storm surge and marine inundation of the area during Hurricane Audrey (Valentine, 1976).

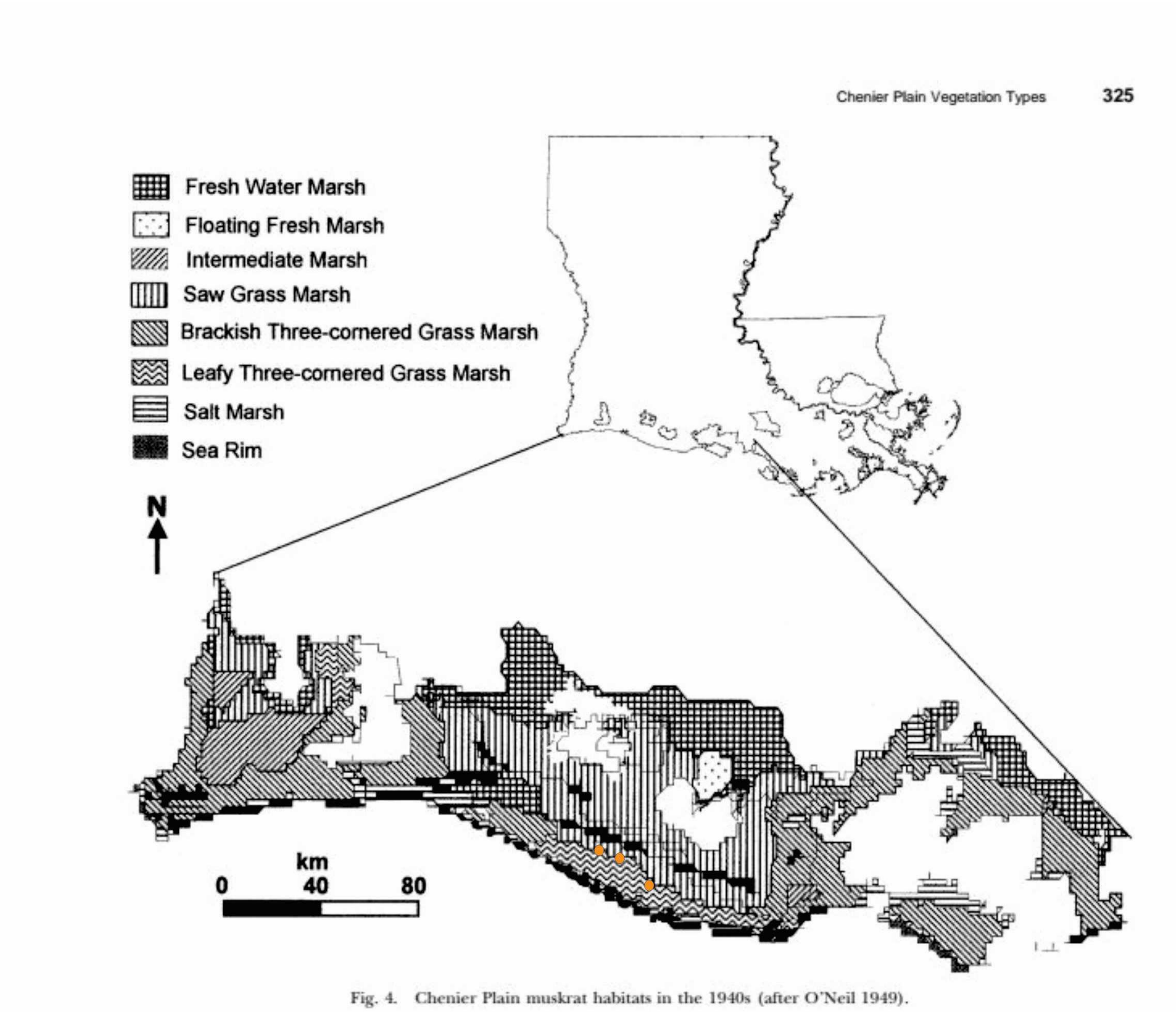

Figure 8. Reproduced from Visser et al, 2000. Created from wetland muskrat habitat as described by O'Neil (1949). Core location sites indicated with orange dots.

According to wetland habitat classification by O'Neal 1949, the area around White Lake and Grand Lake and extending south between Grand Chenier and Pecan Island was dominated Saw grass (*Cladium jamaicense*, C_3) with other freshwater, intermediate and brackish sub-dominants such as leafy three-square (*Bolboschoenus robustus*, C_3) and bulltongue (*Sagittaria lancifolia*, C_3). These plants are typically low salinity plants, an indicator of environmental conditions over the past century.

Historically the sites are located within the sawgrass habitat but near the southern extent that transitioned into leafy-three corner grass marsh (O'Neal, 1949). Currently the sites are located in the southern extent of the habitat classified as oligohaline wiregrass and is dominated by *Spartina patens* (Visser et al, 1999). The sites' changes in vegetation over the last century, as well as its location near a coastal habitat transition, will be analyzed for their relative influences to the organic matter of the bulk content of the soil.

Geochemical Proxies

Geochemical proxies have been useful in reconstructing millennia long paleoenvironmental records in various coastal locations and environments (Lamb et al., 2006; Meyers, 1997). Particularly carbon isotope ($\delta^{13}C$) and C/N ratios have been used to identify organic carbon sources (Fig. 1). Due to the diverse physiology of plants and the way they uptake and assimilate carbon, preserved organic carbon source can be distinguished from C_3 and C_4 plants, and marine and lacustrine algae (Fig. 1). Meyers (1997) notes that use of both $\delta^{13}C$ and C/N improves identification in coastal areas where contributions of organic matter are from algae, C_3 and C_4 plants. Coastal sediments receive organic material from autochtonous sources, derived from *in situ* sources, such as wetland plants and algae, and allochtonous sources, or organic material transported to the sediment, such as tide or storm surge. Preserved isotopes provide an opportunity to unravel the complex nature of estuarine sedimentation processes.

Carbon has two stable isotopes, ^{12}C and ^{13}C. These isotopes have similar chemical properties but their difference in mass causes discrimination against ^{13}C during photosynthesis, which is then recorded in the tissues of plants. The ^{13}C to ^{12}C ratio is expressed in delta (δ) notation with reference to a standard material. The $\delta^{13}C$ ratio is expressed as

$\delta^{13}C = (R_{sample}/R_{standard} - 1)*1000$,

in parts per thousand (‰), where R_{sample} and $R_{standard}$ are the $^{13}C/^{12}C$ ratios in a sample and standard, respectively (McCarroll and Loader, 2004). Carbon isotope fractionation occurs within plant tissues as CO_2 is assimilated during photosynthesis. C_3 plants, C_4 plants and algae each use different mechanisms and processes to capture and use the carbon. C_3 plants utilize the enzyme Rubisco during photosynthesis. Rubisco is inefficient and discriminates against the heavier $^{13}CO_2$ resulting in organic matter that is depleted in ^{13}C compared to the atmosphere. This increased fractionation from the already depleted atmosphere ($\delta^{13}C$= -7 to -8 ‰) results in a further depleted value of approximately -27 ‰ (Deines, 1980). C_4 plants use an additional mechanism, the Hatch-Slack pathway, resulting in less discrimination against $^{13}CO_2$ and a higher $\delta^{13}C$ value of approximately -14 ‰ (O'Leary, 1988). The C_3 photosynthetic pathway is represented in about 90% of all terrestrial plants (Lamb et al., 2006). C_3 plants also dominate freshwater marsh habitats. C_3 plants dominate freshwater habitats in Louisiana's coastal wetlands and C_4 grasses dominate intermediate, brackish and saline marshes. The varying physiology among plants and the way they are preserved within the ecosystem leads to a diverse suite of $\delta^{13}C$ and C/N values from different organic matter sources; therefore, changes in the isotope ratios throughout time can be important biological indicators of plant communities' responses to environmental change.

This study expands on previous reports of $\delta^{13}C$ values of sedimentary carbon in Louisiana coastal marshes. Chmura et al. (1987) identified $\delta^{13}C$ values for fresh, intermediate, brackish and saline marshes as -27.8‰, -22.1‰, -16.9‰ and -16.2‰ respectively. Offshore Acthafalaya and Wax Lake delta sediments were measured at -22.3‰ to -22.6‰ and suspended river sediments were measured at -23.8 to 26.9 ‰ in the Mississippi and

Atchafalaya rivers (Gordon and Goni, 2003). Gordon and Goni's (2003) extensive study of terrigenous OM input to surface deposits of the inner Louisiana shelf, west of the Atchafalaya, was extremely useful. Their study identifies the geochemical markers of one of the main OM inputs to the region, the Atchafalaya's riverine sediments redistributed through the Gulf of Mexico to the Chenier Plain.

3. METHODS

Sample Collection

In winter of 2005 sediment cores were taken with a coring device described in Meriwether et al. (1996). The device is comprised of a 3 in diameter, one-meter long PVC pipe with a sharpened edge held in a rubber plumbing boot with attached handle. The handle is 1.5 in PVC with an open, pluggable top. The handle is hollow to allow air to escape as it is inserted into the soil and water to fill the void above the soil after insertion. A bung or rubber plug is used to seal the top of the handle. The addition of water improves suction when removing the core, as liquid does not expand like gas under negative pressure, allowing the heavy, wet clay core to be removed. Prior to insertion, a sharp knife was used to cut the surface roots around the circumference of the core to eliminate compaction of the core material as the device was pushed down into the soil. The cores were extruded in the field to minimize disturbance from transport. The cores were gently and precisely extruded and sliced into 2 cm vertical increments. Core slices were weighed fresh then dried in a mechanical convection oven at 60° C. The dried material was ground in a Wiley grinding mill, cleaning between samples. The ground material was placed into autoclavable plastic jars and measured for specific activity of ^{137}Cs. Bulk density was determined as the dry weight of a core slice divided by the volume of the slice.

Geophysical Analysis

The specific activity of ^{137}Cs in each slice was determined by gamma ray spectroscopy using high purity germanium (HPGe) detectors. The 662 keV gamma emissions from ^{137}Cs was measured for at least 11 hours. The gamma spectrometers were calibrated for energy and efficiency using a reference mixed gamma ray source (^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sa, ^{137}Cs,

^{88}Y, ^{60}Co) traceable to NIST (Analytics Inc). The specific activity of each sample (A) was calculated using the following expression:

A= C/t mBE

where C is the integrated counts of ^{137}Cs, t is the counting time (in seconds), m is the mass of the sample (g), B is the branching ratio (0.85) for this emission from ^{137}Cs, and E (0.262) is the detection efficiency at 662 keV.

The depth profile of ^{137}Cs was determined by plotting, A, as a function of the depth of the core slice. The centroid of a typical sharp peak is determined by calculating a weighted average of the three points that define the peak, where d = depth of the peak, y = depth, and x = ^{137}Cs specific activity.

$d = \Sigma(yx)/ \Sigma x$

The resulting depth of the ^{137}Cs peak was used to determine rate of long term accretion (cm yr^{-1}) by dividing the depth of the ^{137}Cs peak (cm) by the number of years since peak ^{137}Cs deposition. Three cores were chosen out of the dozens collected in 2006. The cores were chosen based upon being sampled in the same location in 2000 and 2006 and having a clear and consistent ^{137}Cs peak, indicating consistent sedimentation rate. In 2005 Hurricane Rita struck and deposited sediments carried by its storm surge. The storm surge peaked at fourteen feet in the Rockefeller refuge area.

Geochemical Analysis

The rinse method as outlined by Brodie et al. (2011) was used to prepare the samples for analysis. The samples were separated into subsamples of bulk soil and recognizable plant fragments. The preserved plant material was analyzed separately, as it represents selective preservation of particular plant species and plant parts. The dried and ground core slice was homogenized and divided into an aliquot subsampled for identifiable plant fragments and soil. Soil absent of plant material was selected under 10x magnification with a binocular microscope. The subsampled soil was further homogenized and ground into a fine powder with an agate mortar and pestle, cleaning with methanol between samples. The samples were placed in milliliter centrifuge tubes, and then acidified three times using 500 to 750μl of 10% HCl to remove $CaCO_3$. During each acidification, the acid was allowed to remain in the samples for at least 2.5 hours while soaking in an ultrasonic vibration bath. They were shaken with a lab shaker to ensure proper mixing, and then decanted. The samples were rinsed with deionized water three times after each acidification. The lab shaker was used after each decanting and rinsed to ensure proper rinsing after settling when centrifuging. The acidified samples were then dried at 60°C before weighing 2-10 mg into a tin capsule for analysis of $\delta^{13}C$, %C and %N.

4. RESULTS

The δ^{13}C and C/N values measured all correspond to known values of bulk sediment and plant materials available to riverine influenced estuaries (e.g. Brodie et al., 2011; P. A. Meyers, 1997; and Chmura et al., 1987; O. Das et al., 2013). The cores are dominated by 2-8 cm thick, dark, organic rich, peaty layers separated by 2-8 cm thick, light-grey, silt-rich layers. The dark, organic rich layers are dominated by vegetative growth, creating layers of preserved lignocellulose-rich coastal vegetation.

Cores were taken at three sites on a northwest to southeast transect (from NW to SE: Site 5, Site 3, Site 14). The cores ranged from 44 to 56 cm in length and included clay to sand-sized sediments. Each core was sampled at 2 cm intervals for a total of 74 samples. Each sample was analyzed for ^{137}Cs, δ^{13}C value, %C, %N, and bulk density. The core from site 5 had an average organic carbon percentage of 16.01%, while Site 3 averaged 15.14% and Site 14 averaged 3.98%. Sediments ranged from gray to black, consistent with the wide range of % organic carbon measured in the cores (1.4 to 31.0 %C). All three cores contained a ^{137}Cs peak, which was used to constrain sedimentation rates and depositional ages. δ^{13}C values ranged from -27.80 to -16.04 ‰ and C/N ranged from 4.5 to 17.4, consistent with a wide range of source materials, including C_3 and C_4 land plants and marine algae. Bulk density ranged from 0.057 to 0.670 g/cm^3, consistent with highly organic wetland soils. Below, the physical and chemical properties of each core are described.

Site 5

The core from Site 5, which is farthest from the coast and closest to the first inland chenier, Grand Chenier, is 56 cm long and contains clay, silt, and organic matter. δ^{13}C values range from -18.5 to -27.6‰ and average -25.1‰, suggesting the site is dominated by C_3 inputs.

From 18 to 56 cm depth, the $\delta^{13}C$ value is stable at -26.3 ± 1.3‰ and then increases to a high of –18.5‰ at 15 cm depth. From 15 to 10 cm depth, the $\delta^{13}C$ value declines to –22.6‰, reaching a steady value of -22.8 ± 0.18‰ in the uppermost 12 cm of the core. Bulk density showed a narrow range (0.17 to 0.45 g/cm^3), and little trend within the core, with the exception of a single high value of 0.68 g/cm^3 at 4.5 cm depth. From 14 to 56 cm depth, the C/N ratio was stable at 13.7 ± 1.3 followed by a gradual decline to 8.3 ± 0.6 from 0 to 12 cm depth. %C and %N were strongly correlated (r = 0.998) and followed similar trends to each other. The ^{137}Cs peak (year 1963) occurred at 14.4 cm depth, indicating an average accretion rate of 0.35 cm yr^{-1}.

Site 3

The core from Site 3, which is located in the center of the transect approximately equidistant from the coast and Grand Chenier, is 44 cm long, and contains clay, silt, and organic matter. $\delta^{13}C$ values range from -16.3 to -27.8‰ (avg ± 0.12 stdev), and an average of -22.13‰ suggesting the site contains a mix of C_3 and C_4 inputs. From 34 to 44 cm the $\delta^{13}C$ value is stable at -27.4 ± 0.4‰ then increases to a stable value of -22.4 ± 0.6‰ from 22 to 32 cm depth. The $\delta^{13}C$ value then slowly increases to a high of -16.3‰ before decreasing to a stable value of -22.4 ± 0.5‰ in the uppermost 6 cm of the core. Bulk density showed a narrow range (0.06 to 0.17 g/cm^3), and little trend within the core with the exception of the uppermost 6 cm having a higher value (0.24 ± 0.03 g/cm^3). The C/N ratio remained between 10.0 and 17.37, except for the lower values at 42 to 44 cm depth (6.6), 32 to 36 cm depth (6.0 ± 1.2), 10 to 14 cm depth (4.8 ± 0.4) and 0 to 4 cm (8.9 ± 0.1). %C and %N were strongly correlated (r = 0.96) and followed similar trends to each other. The ^{137}Cs peak (year 1963) occurred at 18.9 cm depth indicating an average accretion rate of 0.45 cm yr^{-1}.

Site 14

The core from Site 14, which is closest to the coast, is 50 cm long, and contains clay, silt and organic matter. $\delta^{13}C$ values range from -22.79 to -16.04‰ (avg ± 0.01 stdev), and an average of -18.10‰ suggesting the site is dominated by C4 inputs. From 6 to 50 cm depth the $\delta^{13}C$ value is stable at 17.52 ± 1.48‰ then decreases to -22.33 ± 0.47‰ in the uppermost 6 cm of the core. Bulk density showed a narrow range (0.22 to 0.67 g/cm^3), and little trend within the core with the exception of a higher value (0.83 ± 0.06 g/cm^3) from 2 to 6 cm. The C/N ratio remained between 10.16 and 13.62, except for the uppermost 4 cm (8.67 ± 0.24). %C and %N were strongly correlated (r = 0.99) and followed similar trends to each other. The ^{137}Cs peak (year 1963) occurred at 15.3 cm depth indicating an average accretion rate of 0.37 cm yr^{-1}.

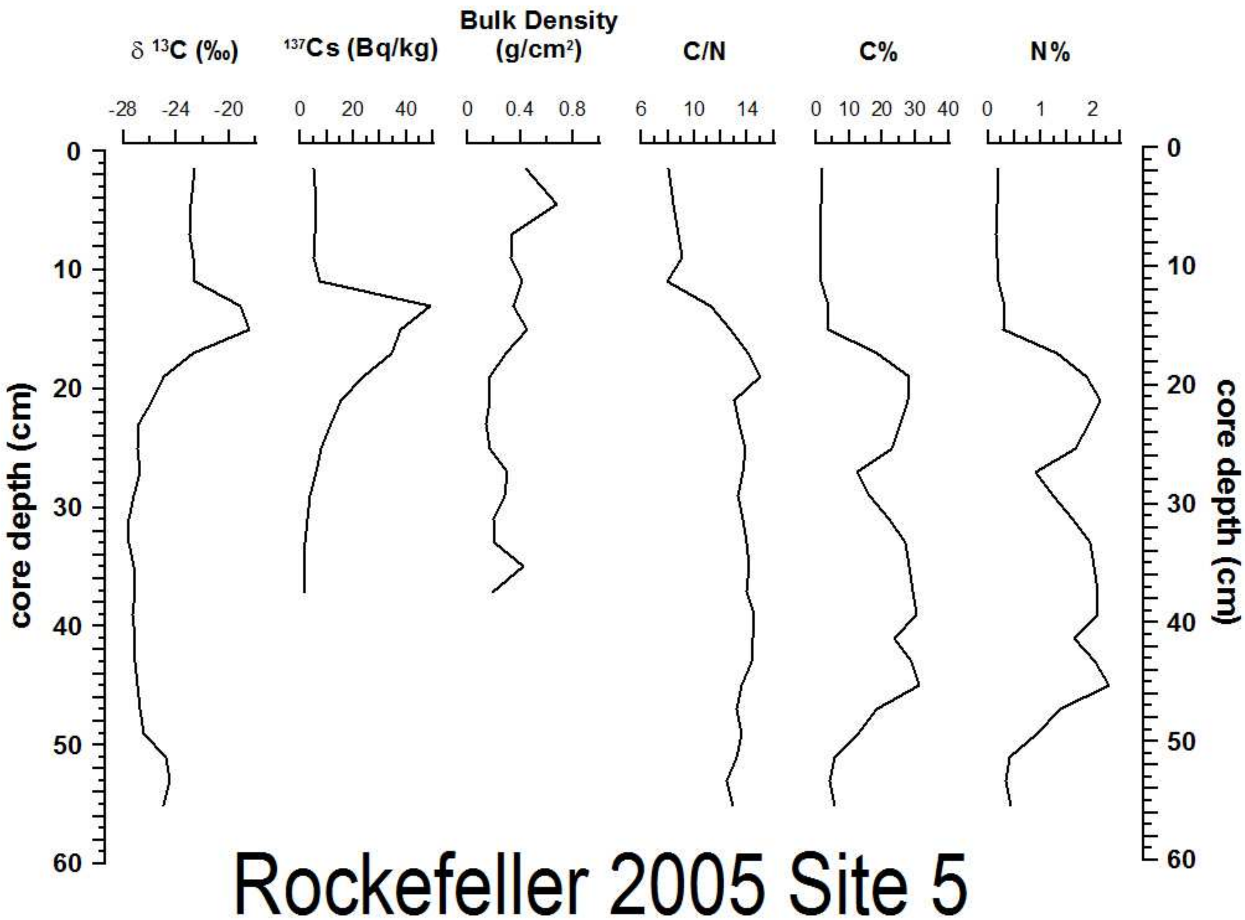

Figure 9. Site 5 core data.

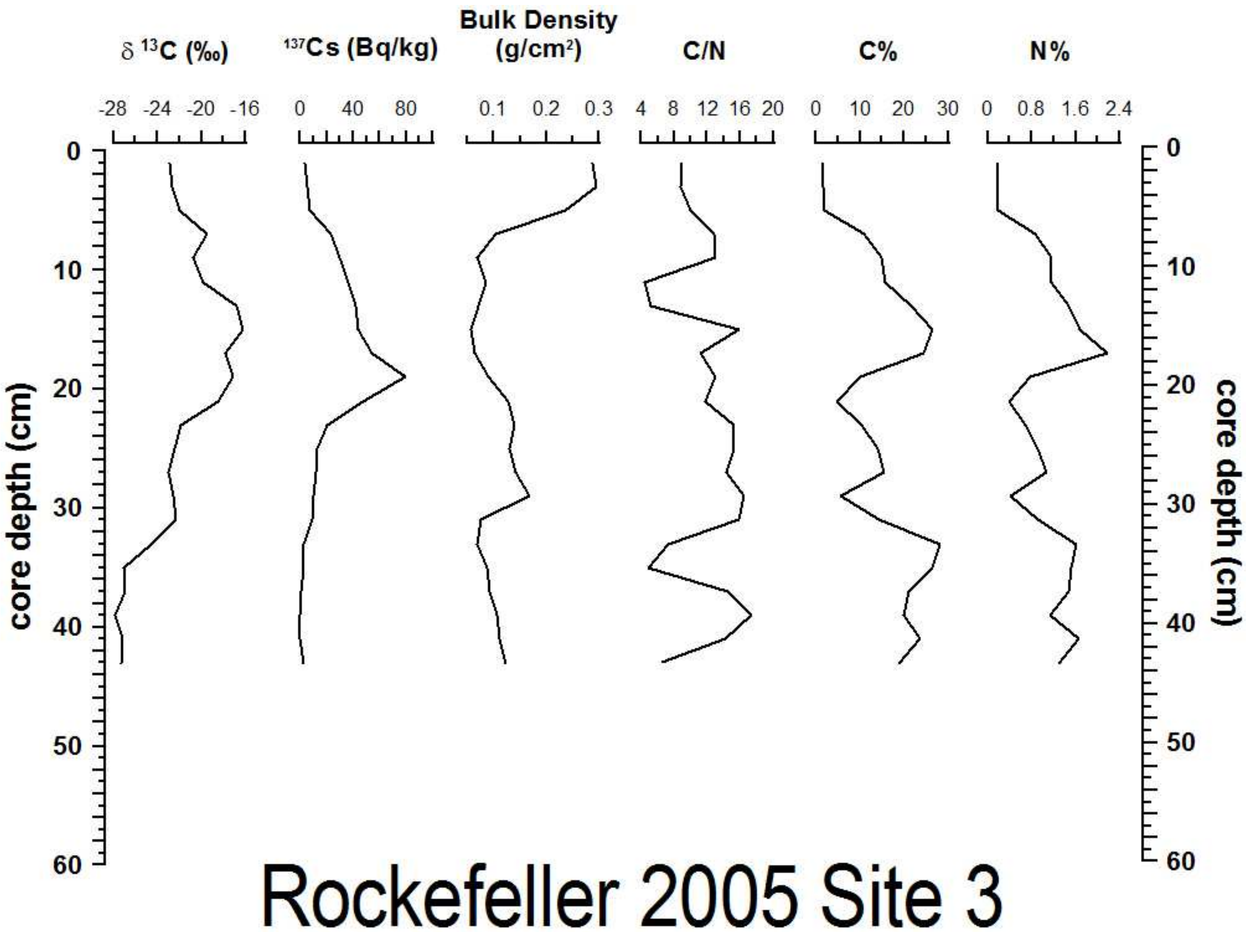

Figure 10. Site 3 core data.

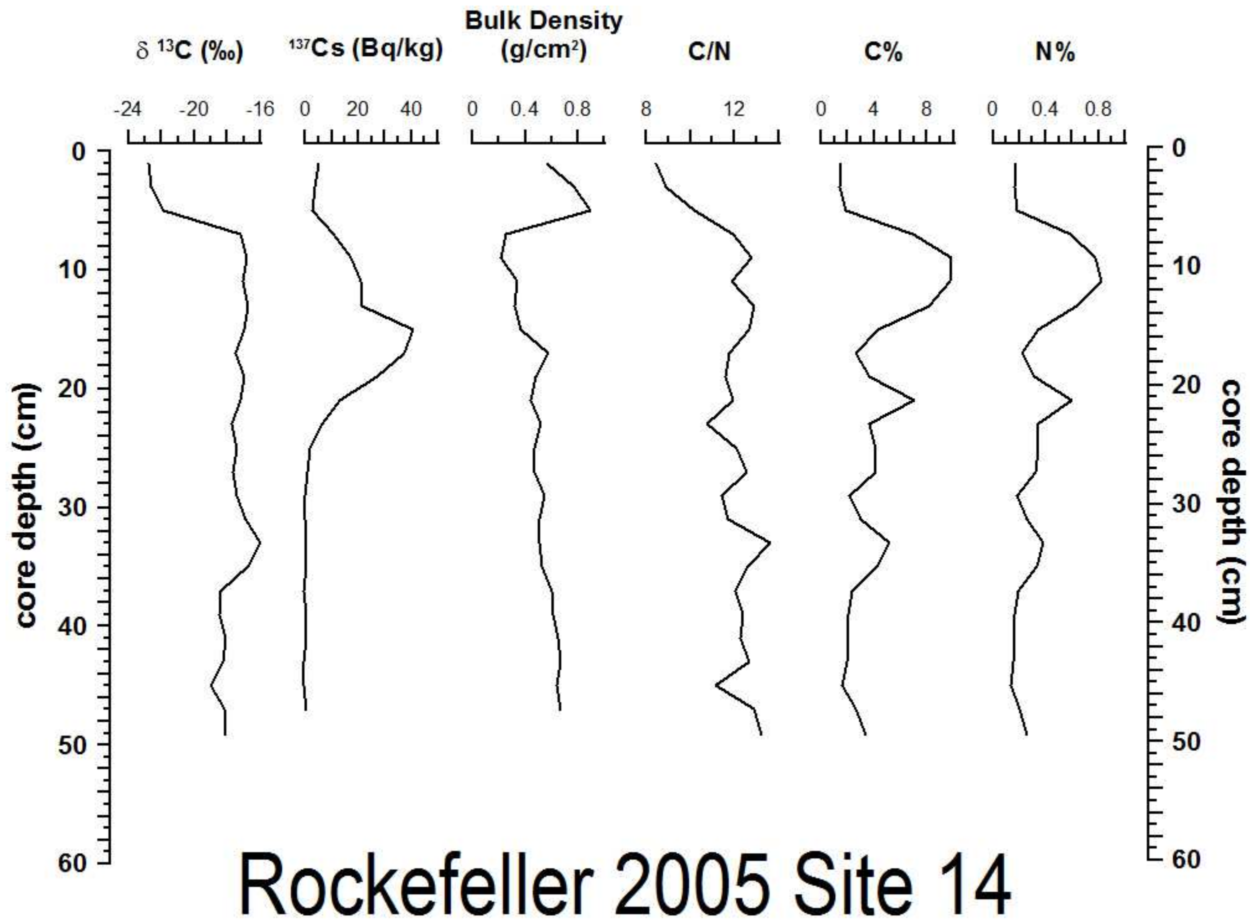

Figure 11. Site 14 core data.

5. DISCUSSION

Land Management Change

A combination of many land use changes has been the driver of habitat change on the Chenier Plain over the last century (Gammill et al., 2002). Human settlement and the adoption of agriculture in the region brought levees, stopped regional scale fires, and widened tidal channels, changing hydrology and increasing salt water influence. The scale of construction of levees for roads and for freshwater storage in the White Lake/Grand Lake basin has fundamentally changed hydrology (Gammill et al., 2002) and thus changed the dominant means of sedimentation and is therefore exhibited by the changes to dominant organic carbon input.

Organic Matter Source Changes

Using one date to constrain the age of the core aids in understanding the average accretion rate of the area. Due to the dynamic nature of storm surge deposition and wetland soil accretion, paleoenvironmental changes do not correlate when a constant sedimentation rate is applied to throughout each core. The differences in accretion rate through time are due to the temporal and spatial dynamic of wetland soil growth. The complex feedback mechanisms described earlier serve to maintain an equilibrium elevation over time as subsidence, accretion, storm surges, and erosion occur simultaneously with dynamic degrees of influence.

The changes observed among all three cores suggest regional changes in organic matter source to Chenier Plain over time. The sites' locations, coastal proximal and coastal distal, have an influence on how they change over time also, due to the differences in tidal and freshwater influence. At the two most inland sites (Sites 5 and 3), we see an increase in $\delta^{13}C$ value that peaks at $-17.39 \pm 1.12‰$, shortly after the 1963 horizon marker (^{137}Cs peak).

Across all three sites, we then see a decrease in $\delta^{13}C$ value from shortly after 1963 to the present value -22.75 ± 0.16‰ at the surface. Bulk density is greatest in all three cores at the surface (0 to 6 cm depth), consistent with storm surge inputs from Hurricane Rita a few months before sample collection.

In 1960 Highway 82, the last major roadway completed on the Chenier Plain, closed a major topographic low linking Grand Chenier and Pecan Island by a highway ridge. By 1967 the highway was hard-surfaced. This prevented sheet flow drainage across the freshwater marshes between the two cheniers. The construction of the road to the north and the construction of deep north-south running canals facilitated the increase in marine influence to the sites. Sites 5 and 3, the two northern and coastal distal cores located within historically freshwater habitat (O'Neil, 1949), have $\delta^{13}C$ values and C/N ratios consistent with a transition from a terrestrial system dominated by fresh C_3 plants to a mixed C_3/C_4 brackish ecosystem (maximum C_4 input approximately 1963), followed by a transition to an intermediate habitat, with increasing fresh influence in the latter 20th century, then an abrupt transition to marine-dominated influence within the storm surge deposit at the surface. These trends are consistent with human hydrologic changes to the Chenier Plain; primarily, deepening of tidal channels and the bifurcation of the Mermentau River basin into two sub-basins allowing tidal influence to dominate in the Chenier sub-basin. And further, hydrologic alteration projects completed in the latter 20th century attempted to re-establish the natural hydrology of the Chenier sub-basin, allowing freshwater influence from the north to once again provide significant input to the Chenier sub-basin. Site 14 is closer in proximity to the coast and lies on the northern edge of the intermediate habitat and south of the freshwater habitat described by O'Neil, 1949. Site 14's organic matter is dominated by autochtonous C_4

grass from 6-50 cm. The storm surge deposit, uppermost 6 cm of the core, showed $\delta^{13}C$ and C/N values consistent with marine organic matter. The lack of any storm surge deposits showing marine signals at depth is indicative of the dynamic nature of wetland soil growth processes. The vegetation grows roots into the newly-deposited storm surge sediment and utilizes the nitrogen, abundant in marine ecosystems, thus assimilating some of the marine indicators and decreasing the bulk density over time due to vegetative colonization. The storm deposit represents a thicker deposit of the same Atchafalaya sediment deposited on the inner shelf available during normal tidal processes indicated by the $\delta^{13}C$ value (Gordon and Goni, 2003). The marine signal is evident in the most recent storm surge deposition but quickly becomes diluted wetland soil growth processes. Extensive root growth within actively accreting wetland soils serves to spread the signal vertically, dampening the peak, as roots penetrate and change the overall carbon makeup.

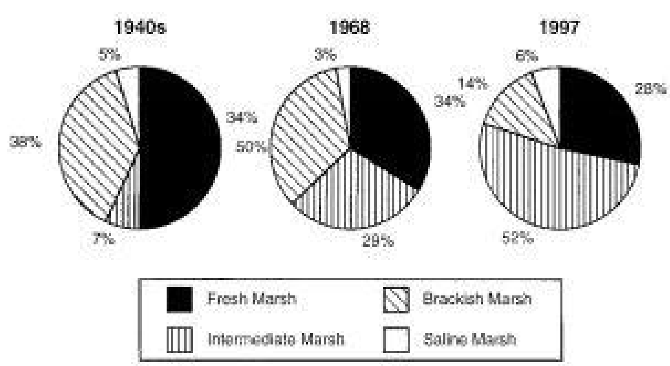

Figure 12. Reproduced from Visser et al., 1999 showing change in percent habitat cover from the 1940's to 1997 on the Louisiana Chenier Plain.

Changes in dominant organic matter input and vegetation types on the Louisiana Chenier Plain are evident in the changes in organic geochemical proxies over the past century. Each site's specific changes occur as follows:

Site 5, located 2 miles south of the eastern end of Grand Chenier, has an accretion rate of 0.35 cm yr^{-1}. Considering constant sedimentation rates, the core represents 160 years, 1845-2005 A.D. The data shows freshwater particulate organic carbon, dissolved organic carbon, and C_3 terrestrial plants as the dominant source of organic carbon from 18-56cm, having $\delta^{13}C$ values below -24.00‰. C/N values above 12 indicate a greater influence by C_3 plants and dissolved organic carbon. Then from 18 to 12 cm depth the signal transitions into brackish marsh dominated habitat contemporaneous with the with the ^{137}Cs peak in 1963 at 14.4 cm deep. $\delta^{13}C$ values above -18.00 ‰ indicate the increasing influence of C_4 grasses (e.g. Chmura et al., 1987; Lamb et al., 2006) occurring during the timeframe of the construction and completion of Highway 82 in 1960. A lower $\delta^{13}C$ value from 10 to 12 cm indicates an increasing freshwater influence. At the surface (0 to 10 cm) marine organic matter is indicated by $\delta^{13}C$ values below -20.00 ‰ and C/N below 10, due to marine organic carbon being less cellulose rich. The storm surge deposit (0-10 cm) has $\delta^{13}C$ values that correspond to sediments deposited on the continental shelf by the Atchafalaya River immediately proximal to the study sites, measured by Gordon and Goni, 2003.

Site 3, located 1 mile south and 3 miles east of Site 5, centrally between Grand Chenier and the coastline, has an accretion rate of 0.45 cm yr^{-1}. Considering constant sedimentation, the core represents 96 years, 1910-2005 A.D. The data shows freshwater particulate organic carbon, freshwater dissolved organic carbon and C_3 terrestrial plants as the dominant source of carbon from 22 to 44 cm depth. The signal then transitions into brackish marsh, dominated by C_4 terrestrial plants from 10 to 22 cm depth contemporaneous with the 1963 ^{137}Cs peak at -18.9 cm and the construction and completion of Highway 82 in 1960. From 10 to 6 cm depth the signal then briefly transitions to more freshwater organic carbon dominated evidenced by intermediate $\delta^{13}C$ values and a C/N ratio of 12.93 ± 0.85. Hurricane Rita's storm surge deposit at the upper 6 cm has a relatively increased bulk density value and $\delta^{13}C$ value that is consistent with shelf sediment just offshore the Chenier Plain measured by Gordon and Goni, 2003. Two other low peaks of C/N, occurring at 10-14 cm and 32-36 cm, did not correspond to a change in $\delta^{13}C$ values, indicating temporary increases marine organism productivity or possible dry periods of aerobic respiration and decomposition of in situ carbon.

Site 14 has an accretion rate of .37 cm yr^{-1}. Considering constant sedimentation rate the core represents 132 years, 1873-2005 A.D. The site is located roughly 2 miles east and 4 miles south of Site 3 on the edge of the habitat transition between oligohaline wiregrass to the north and mesohaline mixture to the south. $\delta^{13}C$ values from 6-50 cm remain consistently above -19.00 ‰ and C/N remains above 10 indicating a habitat dominated by brackish C_4 terrestrial grasses (Lamb et al., 2006). This indicates the site has remained brackish since 1873. The Hurricane Rita storm surge deposit of the upper 6 cm has a relatively increased bulk density value and $\delta^{13}C$ value of -22.4 ± 0.5‰, corresponding to shelf sediments just off the coast of the Chenier Plain measured by Gordon and Goni, 2003. No distinct layers of storm sediments are identifiable downcore in the data, indicating the processes of autochtonous wetland soil growth serve to mask and redistribute the signals over time.

Cores were taken in 2000 C.E. and then in 2005 C.E. in the same locations to investigate the effects of Hurricane Rita. The ^{137}Cs peaks are compared below in figure 13. The difference in each peak is equal to the projected accretion rate over 5 yr for each core plus 6 cm (storm surge deposit thickness). The thickness of a 6 cm deposit across Rockefeller Refuge was determined by Dr. Meriwether after the collection of two 8 km transects on the eastern and western side of the refuge before and after Hurricane Rita (Meriwether et al., 2008, personal communication).

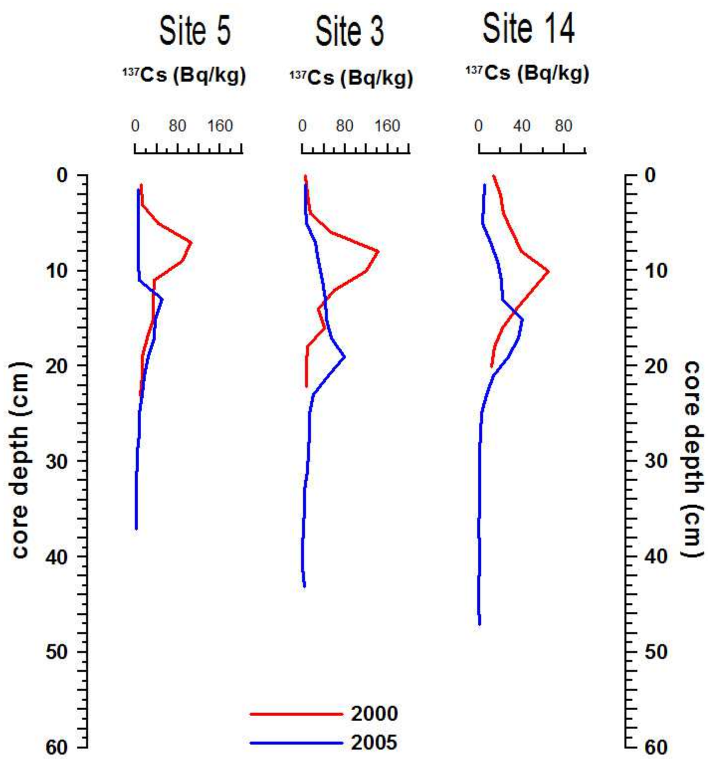

Figure 13. Cesium-137 marker horizon peak signifying the year 1963 C. E. The difference of the peaks is equal to the normal accretion rate over 5 years plus the Hurricane Rita storm surge deposit.

In Dr. Meriwether's analysis of the transects taken in 2005, he calculated the mass of the deposit using the following equation. Where the average mass of the upper 6 cm of all the cores taken after Hurricane Rita was 185 g. The cross-sectional area is equal to 160 g/cm^2. When these values are applied to the area of Rockefeller Refuge the calculated mass of the storm surge from Hurricane Rita would be an estimated 3.5 x 10^9 kg.

$$\frac{185g}{160cm^2} \times \left(\frac{100cm}{m}\right)^2 \times \left(\frac{1kg}{1000g}\right) = 11.6\frac{kg}{m^2}$$

$$30{,}400ha \times \frac{(100m)^2}{ha} = 3.04 \times 10^8 m^2$$

$$11.6\frac{kg}{m^2} \times 3.04 \times 10^8 m^2 = 3.5 \times 10^9 kg$$

6. CONCLUSION

The coastal wetlands of the Chenier Plain experience influence from many different sources that can change in relatively short periods of time. The intricacies of wetland habitat growth and nature can be lost to its own very dynamic growth processes as sediment is so quickly buried. The sediments deposited in these environments offer a valuable opportunity to investigate recent climate, sea-level changes, and land-level changes (Lamb et al., 2006). Other proxies such as microfossils can be inconsistent and/or absent through the entire record. In estuarine environments rich in carbon, $\delta^{13}C$ values and C/N values provide an opportunity to study carbon sources to the coast. The types of sources include freshwater and marine dissolved organic carbon, freshwater and marine particulate organic carbon, freshwater and marine algae, as well as bacteria, C_3 terrestrial plants, and C_4 terrestrial plants. The sources of these types of organic carbon also vary between the riverine Atchafalaya sediment deposited on the continental shelf, dissolved organic carbon from the marine gulf, and the vast freshwater wetlands to the north. The sources' dominance changes frequently within the coastal estuaries, creating a record of their relative influence as their relative productivity changes through time. The current dominant habitat vegetation type of wiregrass marsh is represented in the core sample directly beneath the storm surge deposit. Site 3 and Site 5 showed a transition over the 20th century from a freshwater vegetation habitat dominated by C_3 plants to an intermediate vegetation habitat that includes a mixture of C_3 and C_4 plants. This indicates that these sites are experiencing relatively more influence from tidal processes, and a relative decrease in freshwater sources, thus increasing intermediate marsh habitat. This is consistent with the increase in intermediate marsh habitat described by Visser et al., 1999. Hydrology change and habitat changes over the last century as described in the 2002 Hydrologic Investigation of the Chenier Plain (Gammill et al., 2002) and Marsh Vegetation Types of the Chenier Plain, Louisiana, USA (Visser et al., 2000) are evident in the changes within organic carbon stored in sediments in the Chenier Plain. Deepening tidal channels and restricting north to south freshwater flow increases the marine influence, while dredged rivers, canals, and hydrologic restoration projects increase the relative freshwater influence. Storm surge sediment provides a significant source for vertical accretion in the area. The storm surge deposit consists of Atchafalaya and Mississippi sediment transported inland from the continental shelf. The organic geochemical proxy approach as described by Lamb et al., 2006 serves as an extremely useful tool for examining habitat change and the influence of terrestrial and marine organic matter as sources to the coastal wetland sediments of the Chenier Plain in coastal Louisiana.

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APPENDIX

Raw data of elemental and stable carbon isotope analysis from the three cores used in this study, and raw data of ^{137}Cs analysis from cores taken at the sites in 2000 C. E.

Supplementary Table 1. **Raw core data from Site 5.**

Mean Depth	$\delta^{13}C$ (VPDB)	+/- $\delta^{13}C$ (VPDB)	Cs-137 spec act (Bq/kg)	+/- spec act (Bq/kg)	Bulk Den. (g/cm3)	C/N	C%	+/- C%	N%	+/- N%
1.5	-22.59		5.0	0.9	0.443	8.03	1.64		0.20	
4.5	-22.88		5.8	0.5	0.680	8.38	1.47		0.18	
7	-22.95		5.7	0.7	0.335	8.80	1.43		0.16	
9	-22.75		4.9	0.6	0.331	9.07	1.45		0.18	
11	-22.60		7.3	0.6	0.415	7.98	1.51		0.19	
13	-19.11		49.3	0.8	0.346	11.24	3.62		0.32	
15	-18.50	0.158	37.9	0.7	0.449	12.75	3.60	0.164	0.29	0.005
17	-22.71		34.3	0.9	0.291	14.04	18.30		1.30	
19	-24.99		23.6	1.3	0.170	14.98	28.08		1.87	
21	-25.79		15.5	1.2	0.171	13.05	27.82		2.13	
23	-26.85		11.5	1.5	0.137	13.40	25.55		1.91	
25	-26.89		7.8	1.1	0.168	13.89	22.86		1.65	
27	-26.79		6.1	0.7	0.296	13.67	12.28		0.90	
29	-27.20		3.5	0.7	0.278	13.30	16.30		1.23	
31	-27.61				0.201	13.66	21.94		1.61	
33	-27.61		1.9	1.1	0.211	13.99	27.13		1.94	
35	-27.22				0.424	14.12	28.22		2.00	
37	-27.15		1.7	1.0	0.195	13.99	29.13		2.08	
39	-27.31					14.52	30.18		2.08	
41	-27.17					14.47	23.71		1.64	
43	-27.08					14.31	29.00		2.03	
45	-26.89					13.54	31.01		2.29	
47	-26.77					13.26	18.26		1.38	
49	-26.51					13.56	12.70		0.94	
51	-24.74					13.17	5.43		0.41	
53	-24.53					12.41	4.25		0.34	
55	-24.97					12.94	5.48		0.42	
Mean	-25.12	0.158	13.9	0.9	0.308	12.61	16.01	0.164	1.17	0.005

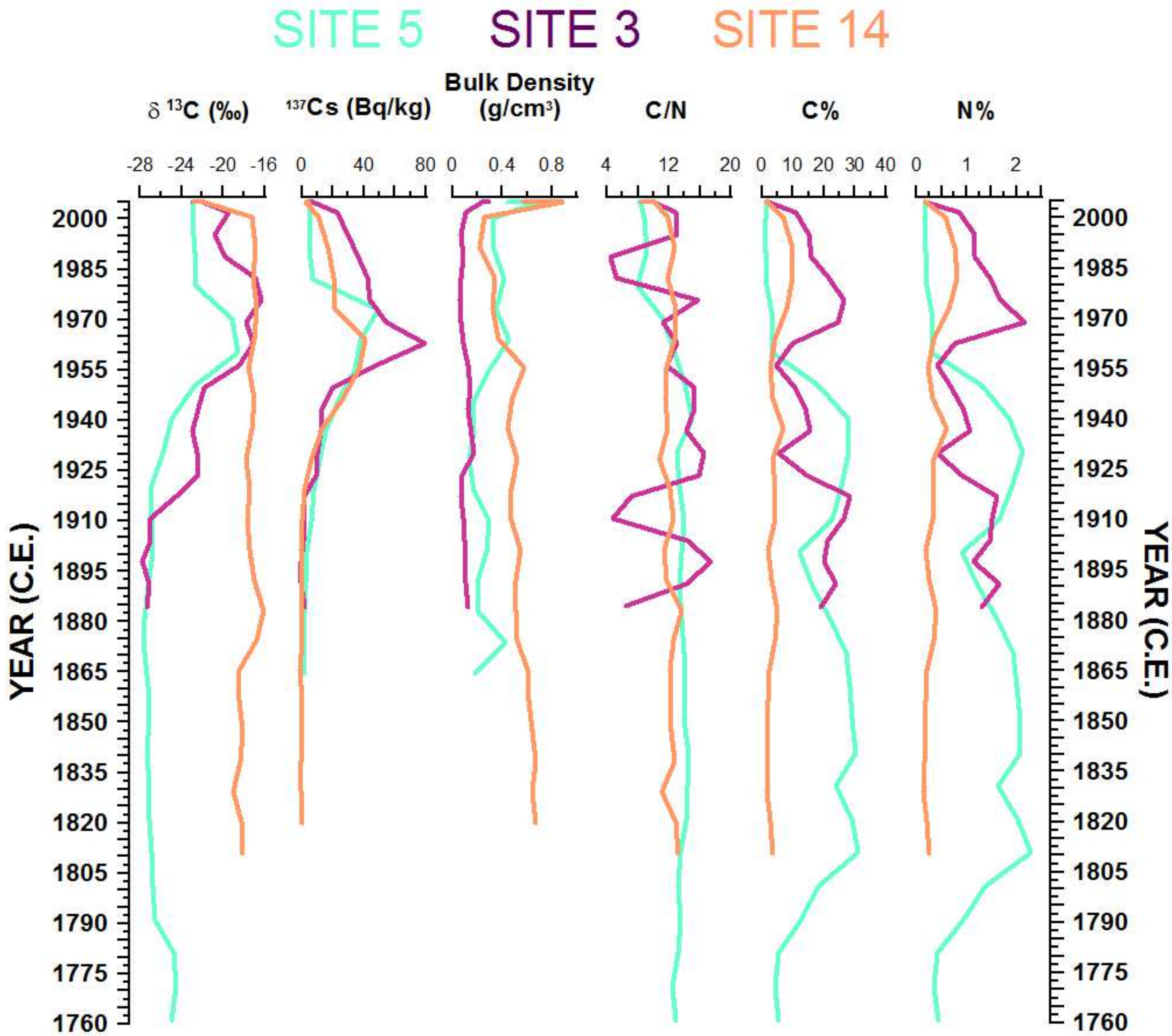
Supplementary Table 2. Raw Core data from Site 3.

Mean Depth	$\delta^{13}C$ (VPDB)	+/- $\delta^{13}C$ (VPDB)	Cs-137 spec act (Bq/kg)	+/- spec act (Bq/kg)	Bulk Den. (g/cm3)	C/N	C%	+/- C%	N%	+/- N%
1	-22.90	0.061	3.8	0.5	0.288	8.91	1.70	0.107	0.19	0.001
3	-22.64	0.059	5.0	0.4	0.296	8.81	1.72	0.001	0.20	0.000
5	-21.99	0.082	7.1	0.5	0.237	10.04	1.85	0.092	0.18	0.005
7	-19.47	0.193	22.7	1.1	0.104	12.84	11.07	0.125	0.86	0.006
9	-20.76	0.121	29.4	1.6	0.070	13.01	15.00	0.004	1.15	0.016
11	-19.79		36.2	1.4	0.086	4.47	15.83		1.16	
13	-16.81		42.2	1.5	0.071	5.15	21.74		1.47	
15	-16.27	0.040	43.8	1.9	0.057	15.80	26.40	0.553	1.67	0.031
17	-17.78	0.000	54.2	1.7	0.065	11.23	24.45	1.614	2.18	0.009
19	-17.12	0.105	79.0	1.6	0.089	13.00	10.07	0.519	0.77	0.012
21	-18.47	0.138	47.3	1.1	0.128	11.75	4.75	0.084	0.40	0.007
23	-21.81	0.008	20.0	0.9	0.140	15.30	10.53	0.258	0.69	0.015
25	-22.40	0.138	13.0	0.9	0.129	15.26	14.04	0.304	0.92	0.039
27	-22.96	0.014	12.1	0.8	0.142	14.31	15.38	5.932	1.07	0.396
29	-22.54	0.736	10.4	0.7	0.169	16.48	5.52	4.603	0.41	0.344
31	-22.35	0.124	9.4	1.2	0.076	15.89	14.40	0.303	0.91	0.016
33	-24.56		2.1	1.3	0.069	7.22	28.24		1.61	
35	-27.05		2.0	1.0	0.088	4.80	26.55		1.53	
37	-26.99	0.131	1.0	1.0	0.092	14.45	21.21	1.807	1.47	0.040
39	-27.80	0.049	-0.1	1.0	0.107	17.37	19.90	0.945	1.15	0.049
41	-27.15	0.014	-0.1	0.9	0.110	14.24	23.68	0.587	1.66	0.057
43	-27.30		2.1	0.8	0.123	6.63	19.14		1.33	
Mean	-22.13	0.118	20.11	1.07	0.12	11.68	15.14	1.049	1.05	0.061

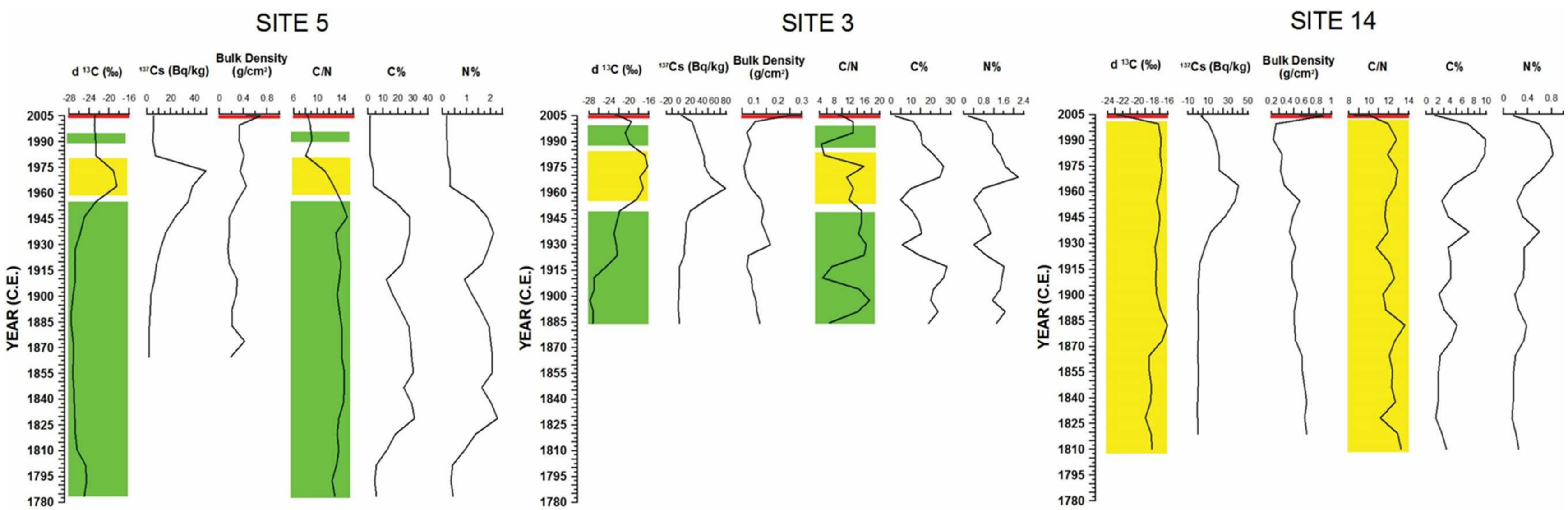
Supplementary Table 3. Raw core data from Site 14.

Mean Depth	$\delta^{13}C$ (VPDB)	+/- $\delta^{13}C$ (VPDB)	Cs-137 spec act (Bq/kg)	+/- spec act (Bq/kg)	Bulk Den. (g/cm3)	C/N	C%	+/- C%	N%	+/- N%
1	-22.79	0.047	5.2	0.4	0.567	8.43	1.50	0.063	0.18	0.002
3	-22.62	0.085	3.4	0.3	0.772	8.91	1.42	0.083	0.16	0.004
5	-21.86	0.141	2.5	0.3	0.889	10.16	1.82	0.044	0.18	0.003
7	-17.25	0.058	10.6	0.8	0.258	11.92	6.96	0.174	0.58	0.005
9	-16.86	0.007	17.2	1.1	0.219	12.79	9.89	0.310	0.77	0.015
11	-17.06	0.051	20.9	0.9	0.337	11.88	9.75	0.333	0.82	0.004
13	-16.72	0.071	21.2	0.8	0.321	12.89	8.19	0.095	0.64	0.011
15	-17.00	0.016	40.6	0.8	0.370	12.69	4.35	0.248	0.34	0.012
17	-17.50	0.012	37.2	0.6	0.572	11.75	2.61	0.126	0.22	0.008
19	-17.02	0.022	26.9	0.6	0.483	11.61	3.64	0.178	0.31	0.014
21	-17.21	0.202	13.1	0.6	0.441	11.92	7.07	3.248	0.60	0.294
23	-17.72		6.5	0.5	0.518	10.73	3.65		0.34	
25	-17.44	0.050	1.7	0.5	0.467	12.07	4.11	0.160	0.34	0.008
27	-17.65	0.169	0.6	0.5	0.474	12.55	4.12	0.159	0.33	0.011
29	-17.47	0.286	-0.1	0.4	0.543	11.45	2.12	0.083	0.19	0.007
31	-16.93	0.051	0.0	0.5	0.507	11.72	2.98	0.231	0.25	0.012
33	-16.04	0.100	0.3	0.4	0.505	13.62	5.16	0.143	0.38	0.013
35	-16.73	0.066	0.1	0.4	0.524	12.61	4.18	0.263	0.33	0.007
37	-18.41	0.368	-0.8	0.4	0.604	12.07	2.31	0.251	0.19	0.010
39	-18.48	0.065	0.2	0.4	0.609	12.37	2.06	0.127	0.17	0.006
41	-18.15	0.201	0.1	0.3	0.644	12.25	2.07	0.320	0.17	0.010
43	-18.30	0.071	-0.7	0.4	0.669	12.68	1.93	0.111	0.15	0.003
45	-18.99	0.060	-0.4	0.4	0.640	11.14	1.61	0.112	0.14	0.002
47	-18.22	0.114	0.2	0.4	0.670	12.87	2.64	0.313	0.20	0.009
49	-18.08	0.044				13.23	3.37	0.260	0.25	0.010
Mean	-18.10	0.098	8.6	0.5	0.5	11.85	3.98	0.310	0.33	0.000

Supplementary Figure 1. All sites with average accretion rate extrapolated into age across the core.



Supplementary Figure 2. Interpretation of the sites habitat type change over time.



Supplementary Table 4. Cesium-137 analysis of core from Site 5 taken in 2000 C. E.

Depth (cm)	Dry Wt (g)	Bulk Density (g/cm^3)	^{137}Cs Spec. Act. (Bq/kg)
0	13.0	0.037	17.8
2	22.8	0.065	17.7
4	31.2	0.088	23.8
6	46.1	0.130	32.7
8	53.2	0.151	41.0
10	47.0	0.133	53.6
12	40.6	0.115	47.5
14	41.9	0.119	12.6
16	47.6	0.135	7.8
18	39.5	0.112	4.8
20	49.4	0.140	3.0
22	74.4	0.211	
24	92.4	0.261	
26	94.3	0.267	
28	48.1	-0.015	
30	58.1	0.164	
32	36.7	0.104	
34	52.1	0.147	
36	61.2	0.173	
38	80.9	0.229	
40	94.6	0.268	
42	84.4	0.239	
44	63.9	0.181	

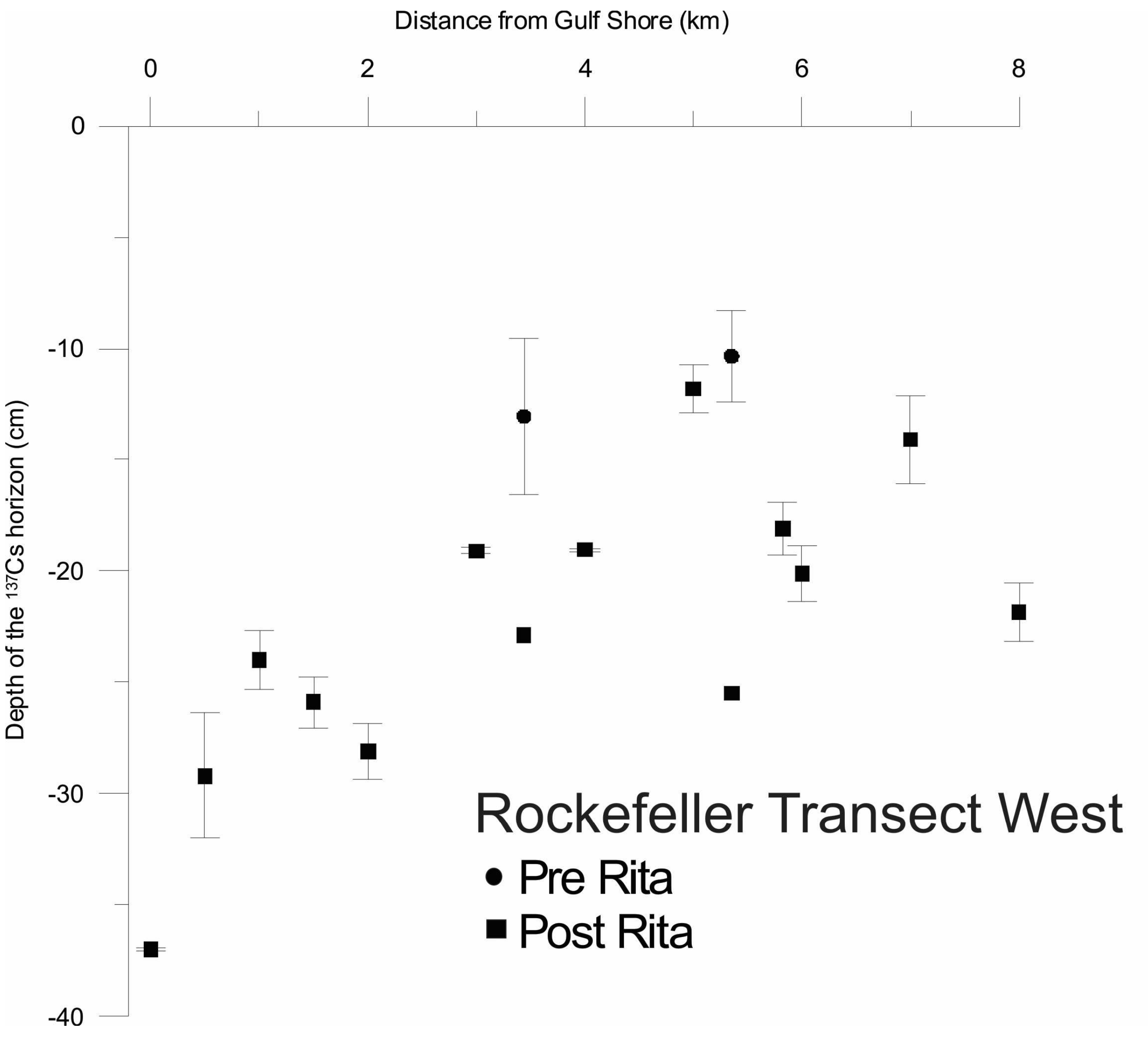
Supplementary Table 5. Cesium-137 analysis of core from Site 3 taken in 2000 C. E.

Depth (cm)	Dry Wt (g)	Bulk Density (g/cm^3)	^{137}Cs Spec. Act. (Bq/kg)
0	14.5	0.041	10.3
2	19.9	0.056	16.8
4	23.6	0.067	20.5
6	24.5	0.069	42.5
8	25.2	0.071	82.7
10	33.1	0.094	107.9
12	58.9	0.167	90.6
14	90.2	0.255	45.6
16	69.9	0.198	29.8
18	41.8	0.119	18.8
20	30.8	0.087	14.9
22	32.0	0.096	11.2
24	45.5	0.129	5.58
26	56.7	0.160	4.35
28	29.7	0.084	
30	44.7	0.127	
32	53.3	0.151	
34	27.3	0.095	
36	32.9	0.093	
38	70.4	0.200	
40	61.5	0.174	
42	63.6	0.180	
44	55.0	0.156	
46	42.7	0.121	

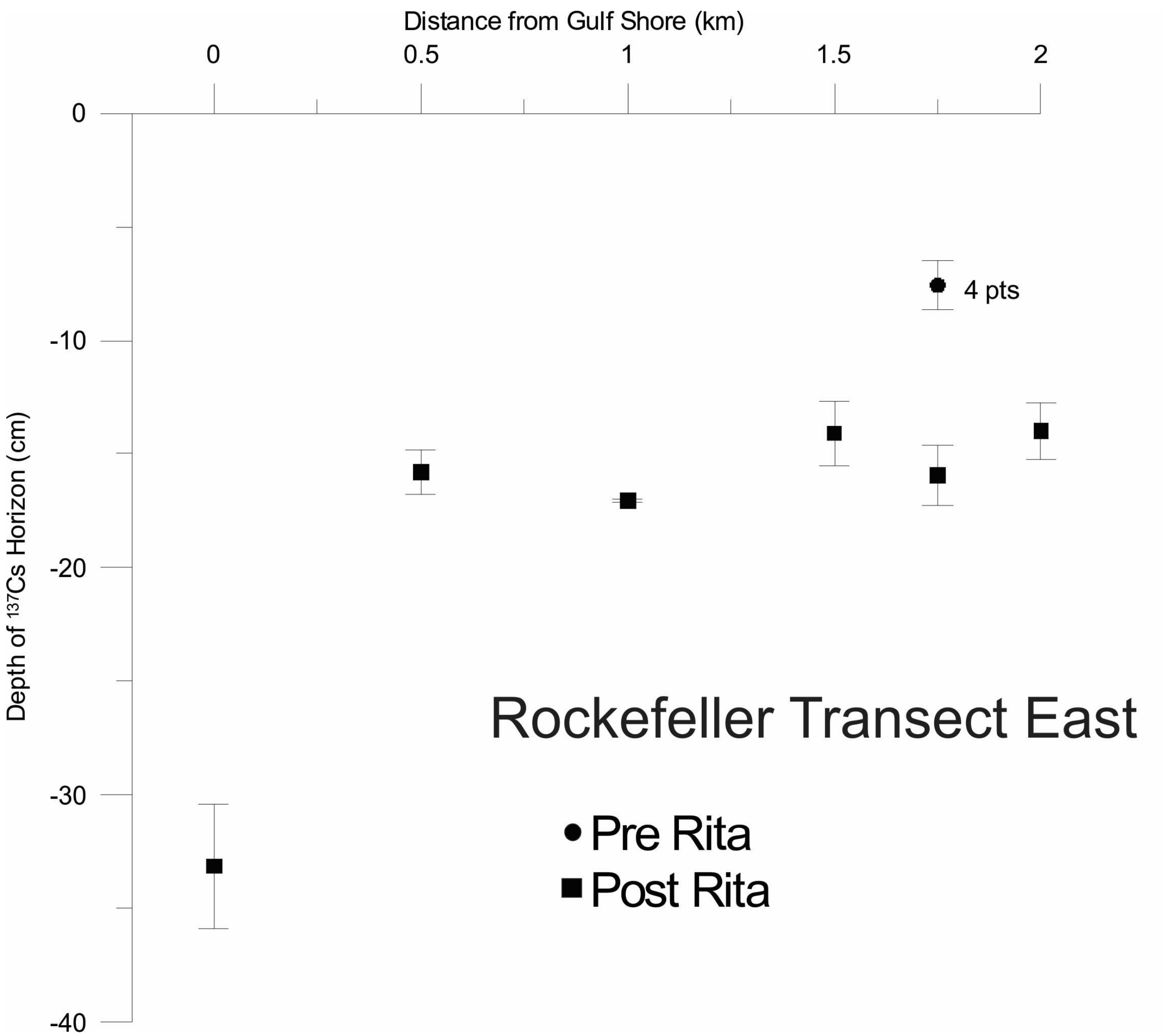
Supplementary Table 6. Cesium-137 analysis of core from Site 14 taken in 2000 C. E.

Depth (cm)	Dry Wt (g)	Bulk Density (g/cm^3)	^{137}Cs Spec. Act. (Bq/kg)
0	34.9	0.099	11.2
2	45.1	0.128	16.3
4	63.1	0.179	25.6
6	54.0	0.153	46.1
8	84.8	0.240	44.3
10	78.5	0.222	38.6
12	82.7	0.234	15.3
14	94.5	0.267	13.9
16	100.4	0.284	8.1
18	92.1	0.261	5.0
20	103.9	0.294	5.5
22	113.5	0.321	
24	124.5	0.352	
26	125.1	0.354	
28	124.4	0.352	
30	131.1	0.371	
32	139.8	0.396	
34	142.8	0.404	
36	144.8	0.410	
38	157.9	0.447	
40	161.8	0.458	
42	141.0	0.399	
44	94.8	0.268	

Supplementary Figure 3. Graph from Meriwether et al., 2008 showing the change in ^{137}Cs peak before and after Hurricane Rita. The difference being equal to average accretion rate over 5 yr (time between coring) plus 6 cm (storm surge deposit).



Supplementary Figure 4. Graph from Meriwether et al., 2008 showing the change in ^{137}Cs peak before and after Hurricane Rita. The difference being equal to average accretion rate over 5 yr (time between coring) plus 6 cm (storm surge deposit).



BIOGRAPHICAL SKETCH

Dale Stephen Nevitt II received a Bachelor of Science in Renewable Resources and Environmental Sciences from the University of Louisiana at Lafayette in the spring of 2014. Dale returned to UL Lafayette in the fall of 2014 to pursue a Master of Science in Geology. Throughout his academic career at UL Lafayette, Dale has worked at the Institute of Coastal Ecology and Engineering, the NASA Regional Application Center, the USGS Wetland and Aquatic Research Center, and The Hise Company. After graduation, he plans to continue enjoying coastal wetlands by fishing and hunting in them.