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Soil Buoyancy as a Potential Indicator of Hurricane Susceptibility in Louisiana Marshes

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Soil Buoyancy as a Potential Indicator of Hurricane Susceptibility in Louisiana Marshes

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Table of Contents

List of Tables

List of Figures

Abstract

Hurricanes rapidly destroy large expanses land in coastal Louisiana marsh. Research shows that freshwater marsh with organic soils experience increased destruction during hurricanes compared to other marsh. A relevant question surfaces, do some restoration projects create marsh similar to marshes that are more susceptible to hurricane damage. This study analyzes soil, bulk density, plant composition, and buoyancy of restoration projects and sites adjacent to those that experienced land loss during Hurricanes Katrina and Rita. Results indicate that high organic matter percentages in marsh soil increases hurricane susceptibility attributed to decreased bulk density and increased buoyancy. Buoyancy is episodic and is highest during late summer months when soil temperature and decomposition are highest. Late summer is typically when most intense hurricanes occur. If marsh is less dense, decomposing, and buoyant when strongest hurricanes hit, then potential for destruction during a hurricane increases. Samples were collected from August 2009 to October 2009.

Keywords: Buoyancy, freshwater marsh, floating marsh, hurricanes

Chapter One: Introduction

1.1 Context

Coastal land loss in Louisiana presently occurs at a rate of about 15-20 square miles annually (Barras, 2008). The present rate slightly decreases from previous estimates of 25-35 square miles per year (Britsch and Dunbar, 1993; Barras et al. 1994). Since the spike of land loss during the mid-1960's to mid-1970's of 40 square miles per year (Britsch and Dunbar, 1993; Morton et al. 2005), the annual land loss rate continued to decline after the 1970's to present estimates (Britsch and Dunbar, 1993; Barras et al, 1994; Barras, 2005) with only a short term, unsustained increase during Hurricanes Katrina and Rita (Barras, 2005). The factors contributing to coastal land loss are both naturally and anthropogenically induced (Penland and Ramsey, 1990; Penland et al. 1990; Morton et al. 2006; Chan and Zoback, 2007). Coastal land loss is defined as the conversion of land to open water including wetlands converted to upland or drained areas, non-vegetated areas such as mudflats, as well as land lost to hurricanes. Coastal land loss also includes the submergence of land through subsidence and sea level rise, deltaic processes i.e., stage in the deltaic cycle, and edge erosion due to canal and pipeline dredging through wetlands (Penland et al. 1990; Britsch and Dunbar, 1993; Chan and Zoback, 2007). Damming lead to a decreased sediment load of the Mississippi River and levees decreased the amount of sediment reaching the surrounding marsh (Kesel, 1988; Templet and Meyer-Arendt, 1988). The Mississippi River provides mineral sediments and nutrients needed for the marsh to vertically accrete, increase the bulk density of the marsh soil, and produce viable wetland vegetation (Day et al. 2007). Hydrologic changes and shoreline erosion is exacerbated by anthropogenic activity through the creation of canals dredged through wetlands for navigation (Turner, 1997; Kennish, 2001). Hurricanes are also responsible for rapid, large scale land loss in coastal Louisiana. In 2005, hurricanes Katrina and Rita caused an increase in water area of 217 square miles (Barras, 2005). If future predictions come to fruition, an increase in hurricane intensity and a possible increase in frequency, though frequency is still uncertain, will occur as a result of global climate change (Nicholls et al. 2007). Predicted global climate changes vary on a regional scale. Water levels, wave height, erosion, flooding and protection failure is expected to increase and exacerbate coastal land loss (Nicholls et al. 2007). The predictions by Nicholls et al. (2007) describe coastal locations in general terms and may be inappropriate to use for effects on a much more specific scale. The predicted changes could vary by coastal type and more specifically by different marsh type.

1.2 Louisiana Marsh Classification

Historically, marsh of the Mississippi River Deltaic Region has been categorized in zones of salt, intermediate, brackish and fresh marsh based on water salinity regimes and plant associations (Penfound and Hathaway, 1938; Chabreck, 1988). Visser et al. (1998) conducted a more detailed analysis of the vegetation communities found in these four zone types and categorizes the communities into an even finer classification based on vegetation type and water salinity. The results concluded that in fact there are nine different vegetation types for marsh found in the Mississippi River Deltaic Plain Region. The nine vegetation types include polyhaline mangrove, polyhaline oystergrass, mesohaline mix, mesohaline wiregrass, oligohaline wiregrass, oligohaline mix, fresh bull tongue, fresh maidencane, and fresh cutgrass. Visser et al. (1998) used classification based on the salinity zones by Odum et al. (1984) and the common name for the most prevalent plant in each location. The new classifications are expansions on the classifications defined by Hathaway (1938) and Chabreck (1970) of saline, brackish, intermediate and fresh marsh. Polyhaline mangrove and polyhaline oystergrass fall under the previous definition by Hathaway (1938) and Chabreck (1970) for saline marsh with the plant species combination of *Spartina alterniflora, Juncus roemerianus, Batis maritima, Avicennia germinans,* and *Distichlis spicata* and salinity of 18% with a range of 8-29%. The mesohaline mix and mesohaline wiregrass fall under the brackish classification with a salinity of 10% and a range of 4-18% and the plant community containing *Spartina patens, Scirpus americanus, Scirpus robustus,* and *Eleocharis parvula*. The salinity of the oligohaline wiregrass and oligohaline mix is 4% with a range of 2-8% and a plant community of *Spartina patens, Vigna luteola, Scirpus californicus, Echinochloa walteri, Sagittaria sp., Cladium jamaicense,* and *Phragmites australis* which is the same as the classification for intermediate marsh type. The fresh bull tongue, fresh maidencane and fresh cutgrass have a salinity of 0% and a range of 0-3% and a plant community of *Panicum hemitomon, Hydrocotyle sp., Pontederia cordata, Sagittaria sp.,* and *Althernantera philoxeroide*. The more detailed categories presented by Visser et al. (1998) are important because of the overlap in the vegetation found at different locations and the different plant communities represented in each areas. Vegetation type, salinity of the water, and soil composition are indicative of certain marsh types found in a given location. The different characteristics such as vegetation, salinity, etc. of each marsh type may cause some types to be more susceptible to hurricane damage.

1.3 Hurricane History

Since 1901, 59 storms have made landfall on coastal Louisiana and 11 of the 50 most intense storms to hit the United States in recorded history made landfall in Louisiana (Stone et al. 1997). Since the early 1700’s, 35 hurricanes severely impacted the morphology of Louisiana’s coast (Stone et al. 1997). The 2005 season was the most active hurricane season experienced by the North Atlantic in recorded history (Trenberth and Shea, 2006). Data suggests that an average of about 2 major hurricanes make landfall along the U.S. Gulf or Atlantic coast every 3 years (Blake et al. 2007). Between the years of 1851-2006, 15 of the 20 major hurricanes that hit Louisiana occurred during the months of August and September (Blake et al. 2007). Hurricanes Katrina and Rita occurred during the 2005 hurricane season additional major hurricane strikes include hurricanes Betsy (1965), Camille (1969), and Andrew (1992). These major hurricanes affected the wetlands of coastal Louisiana. The studies in the next section examine the different types of damaged experienced by the wetlands.

1.4 Hurricane effects

Several studies examined the impacts of some of the major hurricanes to hit coastal Louisiana. A post-Hurricane Camille study noted significant damage of roughly 100 hectares of floating marsh. The marsh displayed various types of damage. Some floats were broken, reduced in size, completely destroyed or moved to an entirely different location (Chabreck and Palmisano, 1973). The study done following Hurricane Andrew by Guntenspergen et al. (1995) encompassed seven sites in Terrebonne Parish consisting of freshwater marsh with extensive research done at a sight on Otter Bayou near Jug Lake. During Hurricane Andrew, wetlands displayed various types of damage and seemed to correlate to different marsh types. Lateral compression, ripping and tearing of marsh, and disrupted marsh were all found in the floating fresh and oligiohaline marsh types (Guntenspergen et al. 1995). Disrupted marsh is defined as large intact pieces of marsh moved over some distance and are deposited either upright or overturned in another location (Guntenspergen et al. 1995). The salt marsh to the south of the sites did not experience the ripping, tearing and compression found in the fresher marsh areas to the north. The study by Jackson et al. (1995) showed that intermediate marsh at Jug Lake experienced erosion and conversion to open water. The soils in this location were highly organic and contained layers with 35-75% organic matter in the upper 1 m of soil (Jackson et al. 1995). The Jug Lake site was not thought to be floating before the storm. During the storm, large areas of vegetation were observed floating possibly because of sediment erosion and the shearing of grass roots growing in poorly consolidated mucky layers. Several studies also concluded that altered and impounded freshwater marsh experienced longer lasting and more severe results of hurricane damage (Ensminger and Nichols, 1957; Chabreck and Palmisano, 1973; Conner et al. 1989; Michener et al. 1997).

Freshwater marsh experienced the highest rate of loss during Hurricanes Katrina and Rita. The two storms caused an increase in water area by 217 square miles (Barras, 2005). The total includes loss of freshwater marsh by 122 square miles, intermediate marsh by 90 square miles, brackish by 33 square miles and saline marsh by 28 square miles (Barras, 2005) for the entire coast of Louisiana. This begs the question, why are the rates of loss so much higher for freshwater marsh compared to the other types? The answer to this question is uncertain, but may lie in the differences in soil composition of different marsh types. This thesis seeks to answer this question by examining soil characteristics such as bulk density, organic matter content and buoyancy of the seemingly more sensitive fresh and intermediate marsh types.

1.5 Soil Characteristics

Certain criteria must be met for soil to be classified as wetland soil (Mitsch and Gosselink, 1993). Wetland soil, also known as, hydric soil, is characterized by soil that contains an anaerobic upper layer due to saturation or flooding over a long period of time during the growing season. The soils are further categorized as either mineral or organic. Marsh soil is composed of a combination of mineral matter, organic matter, water and trapped gases and each marsh type contains variable percentages of each component (Nyman et al. 1990; Mitsch and Gosselink, 1993; USDA, 2006). According to Mitsch and Gosselink (1993), organic soil is defined as soil with greater than 20 to 35 percent organic content on a dry weight basis, greater than 12 to 20 percent organic carbon, low pH, low bulk density, high porosity (80 percent), high water holding capacity, low nutrient availability and high cation exchange capacity. Organic soils or histosols are commonly referred to as peats and mucks (USDA, 2006). Organic soils can be determined based on the period of saturation and the ratio of soil organic carbon to the percentage of clay in the mineral fraction. The soil organic matter (SOM) contains carbon, organic components such as tissue from dead plants and animals, products produced as the dead plants and animals decompose, and the microbial biomass (Milne and Heimsath, 2008). Nyman et al. (1990) looked at the relative amount of mineral and organic matter in different marsh types. The two areas studied included an active delta zone marsh (an area that receives freshwater and mineral matter from the Mississippi or Atchafalaya River) and an inactive delta zone marsh (marsh that receives mineral matter from reworked sediments and freshwater from rainfall). How a marsh receives freshwater and sediment seems to determine how much mineral and organic matter will be found in the composition of the soil. Total soil volume contained 4-14% of mineral and organic content (Nyman, 1990). The range for organic matter content is approximately 2.4 percent for fresh marsh and 5.3 percent for saline marsh (Nyman and Delaune, 1991). The mineral matter in marsh soils accounts for 50-90 percent of the dry weight but is only present in 2-7 percent of the soil volume (Nyman and Delaune, 1991). Nyman et al. (1990) determined that bulk density decreased in areas of freshwater marsh and increased in areas of saline marsh due to the amount of mineral matter in the soil. Higher levels of mineral matter found in the soil cause the soil to be much heavier. Certain areas of freshwater, intermediate and brackish marsh with high organic soil matter are buoyant or experience periods of buoyancy due to low bulk density and are known as flotant or floating marsh.

1.6 Floating Marsh

Russell (1942) described floatant marsh as a “marsh rich in plant species tolerant of frequent and sustained flooding, anchored in a relatively thin, matted layer of decomposing vegetable (vegetative) debris that is either truly floating on water or supported by highly aqueous organic ooze”. Sasser (1994) further describes floating marsh as wetlands of emergent vegetation with a mat of live roots and associated dead and decomposing organic material and mineral sediment, that moves vertically as ambient water levels rise and fall. The flotant mat consists of a mat root layer and mat peat layer that float on a layer of free water or a fluid organic layer. Below these layers is a layer of highly decomposed organic matter known as sludge. The substrate contains a thick, root bound, highly organic top layer. The active root, top layer of the substrate in floating freshwater marsh is approximately 40 cm in depth. As the roots decompose, the debris becomes denser and the peat separates from the upper root layer of the mat to form a 10 cm layer of peat. Water lies below the peat layer and comprises the 50-100 cm depths of the substrate. Sludge is the next layer occurring from 100-170 cm and clay has the deepest elevation at 170-200 cm (Sasser et al. 1994), (see figure 1.6.1). Some of the largest areas of floating marsh in North America are found in the Mississippi River Delta Plain particularly in the freshwater coastal marsh areas (Mitsch and Gosselink, 1993; Sasser, 1994). Freshwater floating marsh comprises more than 100,000 ha of the marsh found in the upper reaches of the Louisiana Delta plain (O’Neil, 1949; Sasser et al. 1996). O’Neil (1949) surveyed the floating marsh in the upper regions of the Louisiana Delta plain during muskrat research in the Mississippi River Delta

Region. He described two types of flotant marsh, the freshwater marsh dominated by *Panicum hemitomon* that floated freely and the brackish "trembling prairie" marsh which Sasser et al. (1996) later determined is non-floating. There are two conditions for buoyancy that were found in almost all of the floating marsh sites studied by Sasser et al. (1996). The first condition to produce a floating marsh is low bulk density organic substrate free of mineral sediments, and the second is that the marsh has vegetation with extensive fibrous root systems. These two conditions are met only in fresh or near fresh marshes. Bulk density in all sites sampled fell in the range of 0.1 g/cm^3, and as low as 0.03 g/cm^3 (Sasser et al. 1996). Highly mineral soils typically fall in the range of 1.0-2.0 g/cm^3 (Mitsch and Gosselink, 1993). The organic content ranged from 64 to 90 percent in the study sites of Sasser et al. (1996). In *Panicum hemitomon* dominated freshwater marsh, 90 percent of the total biomass is comprised of plant roots. In the 11 year study by Sasser et al. (1996), *Panicum hemitomon* averaged about 76 percent of the total live biomass in the floating marsh. O'Neil (1949) described the *Panicum hemitomon* marsh grass as the only type of vegetation that could produce the buoyant characteristics found in flotant marsh. *Panicum hemitomon* creates a thick floatant mat and is the predominant species found in these freshwater flotant marsh locations (O'Neil, 1949, Visser et al, 1999, Sasser et al, 2008). Buoyancy was consistent throughout the year except when water levels were extremely low (Sasser et al. 1996). There are other types of vegetation in Louisiana capable of creating a floating mat. *Sagittaria lancifolia* also creates a thick floatant mat but the root system is less extensive and less stable than the *Panicum* mat and buoyancy is highest during summer and fall months with a decrease during winter and spring months. *Eleocharis baldwinii* and *Eleocharis parvula* create a thin mat floating marsh, but were found to float irregularly particularly during winter months and had slightly different substrate characteristics than the *Panicum* mats (Sasser et al. 1996). Freshwater floating marshes with high organic matter in the substrate have lower bulk densities and higher buoyancy than wetlands with higher mineral soil matter (Hatton, 1983). The strength of the organic matter is compromised by natural decomposition which increases erosion susceptibility and fragmentation of the marsh (Swarzenski, 2008).

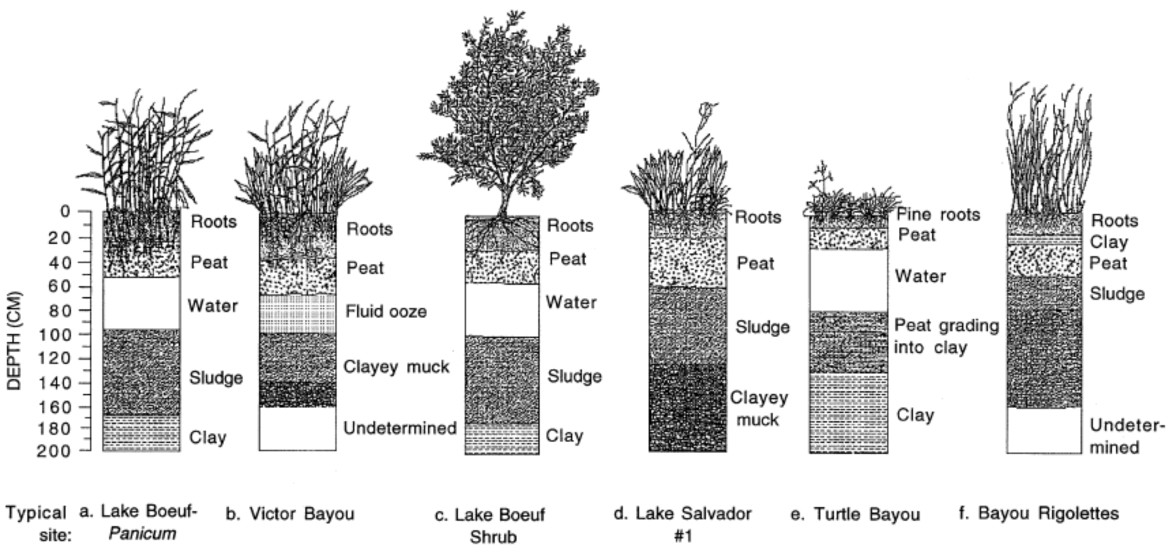

Figure 1.6.1: Vertical depth profiles of substrates at the sites typical of floating marshes (after Swarzenski et al. 1991, and Sasser et al. 1995a; Sasser et al. 1996).

1.7 Decomposition

Decomposition is the chemical decay of detritus or litter through trophic interactions (Adl, 2003). Botanical origin and degree of decomposition are important characteristics of organic soil. Peat is relatively un-decomposed organic soil and muck, on the other hand, is highly decomposed. The botanic origin of the material can come from herbaceous material, moss, wood and leaf litter (Mitsch and Gosselink, 1993). The majority of plant production becomes available to consumers through the pathways of plant decomposition (Mitsch and Gosselink, 1993). Bacteria and fungi attack the vegetation and begin the process of decomposition. The “left over” matter, or humus, is stable organic matter, either difficult to digest or indigestible and can undergo no further decomposition (Adl, 2003). Decomposition changes the characteristics of organic soil. As the peat starts to decompose, the quantity of larger particles decreases through fragmentation (Mitsch and Gosselink, 1993). *Panicum hemitomon,* found in freshwater marsh, has the fastest organic decomposition rate and also has the highest requirement of organic matter needed for marsh soil formation to combat submergence (Nyman and Delaune, 1991). In addition, accelerated decomposition occurs during late summer which creates higher gas content in the substrate, lowers bulk density and increases buoyancy (Hogg, 1988). If some restoration projects create wetlands with highly organic soil experiencing heightened decomposition in late summer months, then are these projects creating wetlands more susceptible to hurricane damage.

1.8 The Effect of Restoration Projects on Marsh Soils

There are many uncertainties on the effects restoration has on marsh soils. Different techniques are used and seem to be successful, but much is unknown on how the soils differ from the natural marsh soils and what effect the differences have on natural marsh functions as well. Two different types of restoration projects were examined in this thesis to determine what type of soils are being created in the two different types of restoration.

One type of restoration involves the use of dredged material to create marsh e.g. Bayou LaBranche wetland restoration. In general, the amount of sediment dredged each year is in the range of hundreds of cubic kilometers (Costa-Pierce and Weinstein, 2002) and material is pumped into lakes, ponds, rivers, oceans, etc or into holding facilities. There are some questions about whether dredged material eventually duplicates the surrounding natural marsh. Dredged material is often not similar to the existing soil in the restoration location. The study done by

Edwards and Proffitt (2003) compared four created and three natural salt marshes in southwest Louisiana and determined if the dredged material marsh eventually transformed into the type of natural marsh found in the reference locations. The results showed that, over time, the created marsh became similar to the surrounding natural marsh in both soil and vegetation aspects in where elevation remained similar. Some areas of created marsh had higher elevations which caused a different species composition. The majority of studies are done on salt marsh and the creation of *Spartina alterniflora* dominated marsh. Edwards and Proffitt (2003) states that if the goal is to create *Spartina alterniflora* marsh then use of dredged material is successful, but that factor alone does not determine function, soil composition or other important attributes for creating a successful marsh restoration. Undefined goals of project success or project results make it difficult to determine if the use of dredged material is beneficial to restoration. A literature review done by Streever (2000) determined from various project data that marshes created with dredged material provide some of the function but may not duplicate all functions of the adjacent natural wetlands.

Another type of restoration project examined in this study is the restoration of natural hydrology in marsh that has undergone hydrologic alterations. Effects on natural hydrology include levees, dams, roadways and canals. Historically, many of these were implemented without realizing the cascading affect it would have one surrounding wetland areas. A study done by Turner and Lewis (1997) summarized the cause and effect relationship between alteration of hydrology and death of surrounding wetland locations. The restoration of hydrology in the sites studied by Turner and Lewis (1997) showed significant improvement in vegetation upon restoration of tidal and freshwater exchange. The Fritchie Marsh project's goal is to return the natural hydrologic patterns to an area of marsh that no longer receives freshwater and nutrient input due to hydrologic alterations.

1.9 Hypotheses

The thesis research presented here seeks to answer questions about the sensitivity of certain marsh types in Louisiana. Studies show that freshwater and freshwater floating marsh experiences some of the most damage during hurricanes. Highly organic fresh inland marsh with a low bulk density seems to experience an increase in wetland loss and deterioration during hurricanes. Theoretically, if a wetland is less dense, decomposing and lighter, then it will more likely experience fragmentation, movement, shifting and overall destruction during hurricanes. Late summer is typically when the strongest hurricanes are formed and decomposition is the highest. The combination of all these elements possibly allows forces from hurricanes to more drastically impact the organic-rich marsh. Some restoration projects may be creating this sensitive marsh type. There should be, as Nyman et al. (1990) states, an optimal ratio of mineral material, organic material and pore space to create structurally sound marsh soil and promote vigorous plant growth as well. This study does not determine what that optimal ratio is, but restoration scientists should seek to create wetland soils that are sustainable and resilient. By creating a certain type of soil with restoration, then project results may be more successful for the long term.

The goal of the project was to determine if certain types of soil are more susceptible to hurricane damage. Several research questions surfaced:

1. Do some fresh marsh soils in the vicinity of those destroyed by Hurricanes Katrina and Rita experience periods of buoyancy in late summer months?

2. What types of soils are associated with different types of restoration projects?

a. Hydrological Restoration
b. Marsh creation with dredged material

3. How are soils in restoration sites different from soils in their corresponding reference sites?

4. Are soils in these restoration projects buoyant during late summer months when the strongest hurricanes hit?

5. Are some restoration projects creating marsh soils that are more susceptible to hurricane damage?

The following hypotheses were generated based on the general research questions presented above. Research conducted during this experiment yielded data to determine the validity of the hypotheses:

H-I: Freshwater marsh surrounding marsh converted to open water during Hurricanes Katrina and Rita has a high percentage of organic matter in the soil.

H-II: Some restoration projects are creating marsh that has a high percentage of organic matter in the soil.

H-III: Freshwater marsh surrounding marsh converted to open water during Hurricanes Katrina and Rita is buoyant during late summer months.

H-IV: Some restoration projects are creating marsh that is buoyant in late summer months.

H-V: The marsh soils with the highest organic matter percentages are the most buoyant.

H-VI: Some restoration projects are creating soils significantly different from their corresponding reference site soils.

H-VII: Marsh soils with the highest organic matter content and highest buoyancy were found in the freshwater marsh sites adjacent to those sites that experienced loss during Hurricanes Katrina and Rita.

H-VIII: Dominant plant species is a good indicator of marsh soil buoyancy and organic matter content.

Chapter Two: Methodology

2.1 Study Sites

Study sites were determined by following several criteria. The first criterion was that marsh type for sites damaged during hurricanes Katrina and Rita was either fresh or intermediate. Several of the sites needed to be in marsh where current restoration projects are located. The Louisiana Department of Natural Resources website and restoration project descriptions were used to determine which restoration projects would be used. Sites were placed in the projects' corresponding reference sites to compare the restoration project marsh soil to the reference site soils using the same project documents. Sites were chosen using aerial photography, a vegetation map and a land loss analysis map following Hurricanes Katrina and Rita.

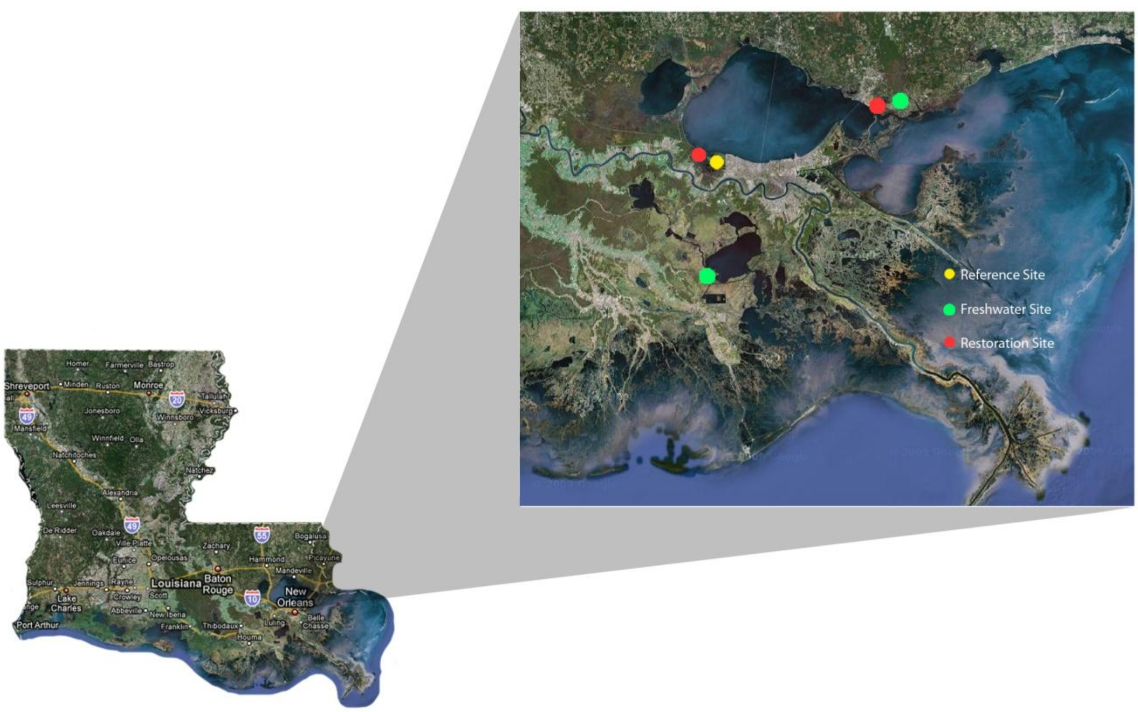

Figure 2.1: Map of Site Locations

Site Name	Site Description
Restoration Sites	
Fritchie Marsh (FM)	Department of Natural Resources (DNR) Restoration Project site northeast of New Orleans, LA
Fritchie Marsh Reference Site	Unable to gain site access to do sampling
Bayou LaBranche (BLB)	Department of Natural Resources (DNR) Restoration project site west of New Orleans, LA
Bayou LaBranche (BLBR) Reference Site	Bayou LaBranche corresponding reference site
Non-Restoration Sites	
Lake Salvador Site (LS)	Freshwater site with areas of damage post Hurricanes Katrina and Rita - located southwest of New Orleans, LA west of Lake Salvador
White Kitchen Site (WK)	Freshwater site with areas of damage post Hurricanes Katrina and Rita - located northeast of New Orleans, LA near the White Kitchen Preserve

Table 2.1: Site Descriptions for restoration and non-restoration sites.

2.2 Site Descriptions

Fritchie Marsh

The Fritchie Marsh restoration project is a hydrological restoration project. The Fritchie Marsh project area contains 2,546 ha of intermediate and brackish marsh located southeast of Slidell in St. Tammany Parish. Natural hydrologic patterns have been disrupted by the construction of the perimeter highways. In addition, saltwater from Lake Pontchartrain enters the marsh through the W-14 canal and Little Lagoon and as a result, the project area has converted from a predominantly fresh marsh to a predominantly brackish marsh. The objective of the Fritchie Marsh Restoration Project is to reduce marsh loss by restoring more natural hydrologic conditions in the project area through management of available freshwater. The following are the goals of the project: decrease rate of marsh loss, increase freshwater flow and promote water exchange into the area from West Pearl River by enlarging the culvert at US Highway 90 and by dredging portions of Salt Bayou, increase freshwater flow into the northern project area by diverting flow from the W-14 canal. By restoring the natural hydrologic cycle, the area will potentially revert back to a freshwater marsh (Hymel et al., 2007).

Bayou LaBranche

The second restoration project is the Bayou LaBranche Wetland Restoration Project (PO-17). Located on the southwestern shore of Lake Pontchartrain, the project area was mostly shallow, open-water habitat, and only a narrow band of marsh along the shoreline between the project and the lake. The goal of the Bayou LaBranche Wetland restoration project was to create new emergent marsh in the open water area of the Bayou LaBranche wetlands using dredged sediment from Lake Pontchartrain (Troutman, 1998).

Lake Salvador Site

The first non-restoration project site is located on the Southwest shore of Lake Salvador and southwest of New Orleans, Louisiana. A series of canals run through the sites of deteriorating freshwater marsh. The marsh surrounding Lake Salvador to the north and east have large expanses of floating marsh dominated mainly by *Sagittaria lancifolia* (Sasser et al. 1996).

White Kitchen Site

The second non-restoration project site is located northeast of New Orleans, Louisiana near the town of White Kitchen, Louisiana. Tributaries off of Pearl River flow through this site and likely input fresh water and mineral sediments to the marsh.

2.3 Experimental Design

Five study sites were chosen and two sub-sites were placed in each study site. The sub-sites were selected in areas of same vegetation type and were not in close proximity to the other sub-sites. Transects were placed in each sub-site parallel to an open water body at least twenty meters from the shore when possible. The transects were selected based on aerial photographs. Along each transect, three plots were placed fifteen meters apart, see figure 2.3.1. The plots are five meters by five meters. Each plot was divided based on a square grid containing twenty five locations, see figure 2.3.2.   Within each plot, five locations were randomly selected for core sampling and vegetation analysis, see figure 2.3.3.

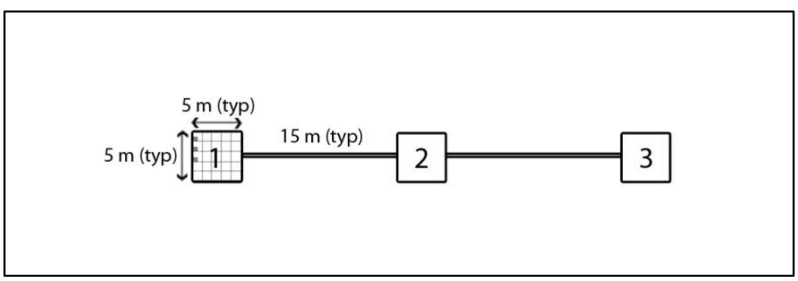

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Figure 2.3.1: Transect and plot layout

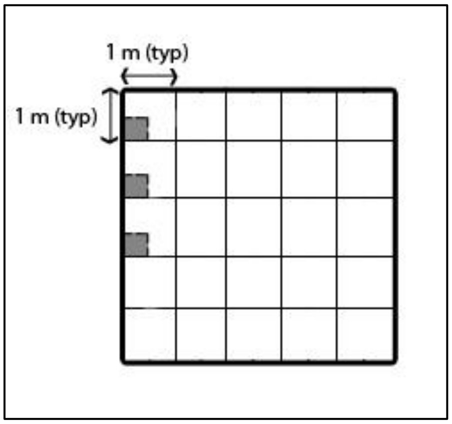

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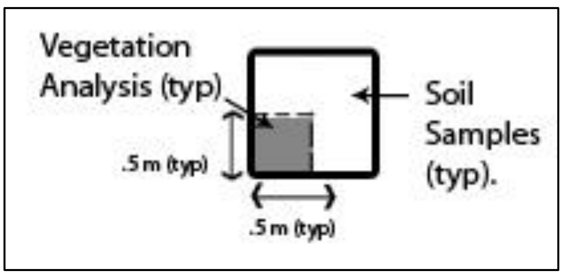
Figure 2.3.2: Plot and location layout



N.T.S.

Figure 2.3.3: Location and vegetation analysis/soil sample layout

2.4 Field Methods

2.4.1 Soil Sampling

In each sub-site, fifteen soil samples were extracted using a Russian peat borer. Nine of the samples gathered were used to test buoyancy, three samples were used to determine organic matter percentages of the soil, and three extra samples were also collected (one from each plot along the transect). The Russian peat borer has a side filling chambered sampler. The "T" handle at the top is turned clockwise and as the borer is turned, the sharpened edge longitudinally cuts a semi-cylindrical shaped sample until the cover plate is contacted. The sample is extruded from the bore by turning it counter clockwise and the sample rests on the cover plate (www.aquaticresearch.com). The next step involves removing the core from the cover plate. Saran wrap was used to cover the sample and the borer is flipped over horizontally. The sample was carefully removed from the cover plate and placed in the saran wrap. The wrap was used to keep the sample intact and to retain some of the moisture. The samples were labeled and inserted into plastic p.v.c. pipes to prevent compaction. The samples were placed in a larger transport container and were processed the same day as sampling to prevent any additional loss of moisture and gas. Sites were sampled from August 2009 to October 2009.

2.4.2 Vegetation Community Identification

Vegetation identification was conducted in the field. The Braun-Blanquet method was employed to determine the percent coverage and plant species found in a half meter by a half meter square in each of the randomly selected locations. A p.v.c. pipe frame one half meter by one half meter was used to determine which vegetation to include in the data. The half meter squared frame was placed in the bottom left corner of each location. To ensure that the vegetation analysis square was in the same place for each location, the first plot started on the left side of the transect and continues to the right until the last plot on the transect. The identification started with the first plot and then continued to right to the second plot along the transect. With this orientation, each half meter square for vegetation analysis occurred at the bottom left corner in each location.

The Braun-Blanquet method that will be used is a measure of degree of cover and species abundance. The p.v.c. frame will be placed in the correct place in the location and the percent coverage of vegetation will be visually estimated using a tool to calibrate the eye. Once coverage is determined, species abundance will be determined within the frame as well. The scale system for percent coverage is as follows from Braun-Blanquet (1932):

1 = very scant (covering less than 1/20 (5%) of the ground surface)

2 = covering $^{1}/_{20}$ (5%) to ¼ (25%) of the ground surface

3 = covering ¼ (25%) to ½ (50%) of the ground surface

4 = covering ½ (50%) to ¾ (75%) of the ground surface

5 = covering ¾ (75%) to $^{4}/_{4}$ (100%) of the ground surface

The scale system used for species abundance is a slight modification from Braun-Blanquet (1932):

1 = very sparse (very rare) less than 5%

2 = sparse (rare) 5% to 25%

3 = not numerous (infrequent) 25% to 50%

4 = numerous (abundant) 50% to 75%

5 = very numerous (very abundant) 75% to 100%

The vegetation within the pvc frame was assigned numbers for percent coverage and a number for species abundance for each vegetation species found within its boundaries.

2.5 Laboratory Methods

2.5.1 Percent organic matter of the substrate

Loss on ignition technique (Dean, 1974; Heiri et al, 2001) was used to determine percent organic matter of the substrate. One sample from each plot was used to find percent organic matter. The cores were cut into 2 cm increments with a serrated edged knife and placed in pre-weighed and recorded aluminum trays. Samples were put in an over set to 60^{o}C overnight. The samples cooled to room temperature before weighing. The weight was calculated by subtracting the aluminum tray weight from the total weight and was recorded as the dry weight.

Using a mortar and pestle, the dried samples were crushed into a fine powder. A brush was used to remove any sediment left in the mortar. After each sample was crushed the mortar and pestle were cleaned and dried before the next sample is processed. Clean, dry and weighed crucibles were used to hold the fine powder. The crucibles and powder were placed in the oven for four to six hours at 60^{o}C. Samples cool and were weighed once again. The crucible weight was subtracted from the overall weight to calculate the sediment weight. Crucibles were then covered with lids and placed in a muffle furnace for approximately sixteen hours at 400^{o}C. Samples cooled for one hour and were reweighed and recorded. This is the ashen weight. The percent organic matter was found using Equation 1:

$$\boldsymbol{LOI_{400} = [(SW_{60} - AW_{400}) / (SW_{60})] * 100} \qquad \textbf{\textit{Eq. 1}}$$

LOI_{400} is the percent organic matter value and is equal to $SW_{60,}$ the sediment weight, minus the AW_{400}, the ashen weight divided by SW60, the sediment weight. The value is then multiplied by one hundred to calculate percentage.

2.5.2 Buoyancy

Buoyancy calculations were done for three core samples from each plot. The core was weighed and recorded upon returning to the lab and remained wrapped in saran wrap to maintain integrity. The sample was then carefully placed in a 4000mL graduated cylinder filled with water to a known volume. The saran wrap was then weighed, recorded and subtracted from the total weight to determine sample weight. The graduated cylinder met accuracy requirements of ASTM class B, E1272 “Cylinder Graduated, Laboratory, Glass”, and all requirements of ISO standard 6706 “Plastic Lab Ware – Graduated Measuring Cylinders.” Once the sample settled in the cylinder, the amount of water displaced by the sample was measured in centimeters, converted to meters for calculation purposes and recorded. The following calculations were used to determine the buoyant force of the marsh core sample.

Several equations are used for determining volume, density, and weight of the water displaced by the marsh core sample. The volume of water displaced is calculated first using Equation 2:

$$\pi r^2 * h_{water\ displaced} = v_{water\ displaced} \qquad \textbf{Eq. 2}$$

Where, πr^2 is the area of the cylinder base, h is the height of the cylinder or the measure of the water displaced and v is the volume of water. Volume is given in cubic meters.

Then, the mass of water displaced is calculated using Equation 3:

$$m_{water\ displaced} = \rho_{water\ displaced} * v_{water\ displaced} \qquad \textbf{Eq. 3}$$

Where $\boldsymbol{m}$ is mass, $\boldsymbol{\rho}$ is the density of water and $\boldsymbol{v}$ is the volume calculated with Equation 2. Density of water at a certain temperature is obtained from a chart (Roberson et al., 1988) of the properties of water and is given in kilograms per cubic meter.

The specific weight of water is obtained from the chart of water properties (Roberson et al., 1988), but is also calculated using Equation 4:

$$\gamma_{water\ displaced} = \rho_{water\ displaced} * g \qquad \textit{Eq. 4}$$

Where, $\boldsymbol{\gamma}$ is the specific weight of water given in Newton per cubic meter, $\boldsymbol{\rho}$ is water density from chart (Roberson et al., 1988) given in kilograms per cubic meter and $\boldsymbol{g}$ is gravitational acceleration. Gravitational acceleration is given in meters per second squared and is defined as the acceleration due to the gravitational attraction of massive bodies.

Once these values were obtained for the water displaced by the marsh core sample, buoyant force was calculated for the object. Buoyant force of an object is equal to the weight of the water displaced by the submerged object. Buoyant force or weight of the water displaced is calculated using Equation 5:

$$w_{water\ displaced} = m_{water\ displaced} * \gamma_{water\ displaced} = BF \qquad \textit{Eq. 5}$$

Where, $\boldsymbol{w}$ is the weight of the water displaced by the submerged object, $\boldsymbol{m}$ is the mass of the water displaced and $\boldsymbol{\gamma}$ is the specific weight of the water. $\boldsymbol{BF}$ is buoyant force of the submerged object.

Buoyancy of the object is determined by comparing the buoyant force of the object to the weight of the object submerged. The weight of the object is calculated using Equation 6:

$$w_{submerged\ object} = m_{submerged\ object} * g \qquad \textbf{Eq. 6}$$

Where, w is the weight of the submerged object, m is the mass of the submerged object and g is the acceleration due to gravity. If the weight of the sample is less than its buoyant force, then the sample is buoyant and will float. If the weight of the sample is greater than its buoyant force, then the sample is not buoyant and will sink.

2.5.3 Data Analysis

The results were compared between the various sites sampled to determine similarities or differences between the mean values of the sites and sub-sites. Mean organic matter, mean buoyant force and mean bulk density were tested for significant differences between sites and sub-sites using a two-way t-test for sample means with unknown standard deviations. A confidence level of 95% was used for all tests. Correlations were examined using regression analysis to determine patterns between bulk density and buoyant force or between organic matter and buoyant force. Results are reported with a mean ± 1 standard error and p values. All calculations and figures were created using Microsoft Office Excel 2007.

Chapter Three: Results and Discussion

The characteristics of marsh in Louisiana vary on many different levels. Plant community, organic matter content, bulk density and buoyancy were examined to determine differences in these properties and how they may affect marsh loss associated with hurricanes. Restoration projects seek to combat marsh loss. Several restoration projects were studied to determine if marsh being created in restoration projects was similar to marsh adjacent to those lost during Hurricanes Katrina and Rita. If the plant communities, organic matter content, bulk density and buoyancy are similar to those marshes with the highest loss, then restoration projects may be creating marsh more susceptible to hurricane damage. Sites were sampled starting in early August 2009 through October 2009. As described in chapter 1.4, these late summer months are typically when the strongest hurricanes hit and when certain types of marsh are most buoyant. The goal of this thesis is to determine if during these late summer months, there is increased hurricane susceptibility due to the marsh possessing a certain set of characteristics that can be used to classify other potentially susceptible marsh sites.

3.1 Organic Matter

H-I: <u>Freshwater marsh surrounding marsh converted to open water during Hurricanes Katrina and Rita has a high percentage of organic matter in the soil.</u>

Soils in the freshwater locations were expected to have high percentages of organic matter. The Lake Salvador (LS) and White Kitchen (WK) sites were chosen to determine the amount of organic matter (OM) found in freshwater marsh adjacent to those areas of marsh loss during Hurricanes Katrina and Rita. These adjacent sites were remaining after Hurricanes Katrina and Rita and may or may not have the same characteristics as the sites that were lost.

The LS sub-sites were found to have considerably higher percentages of OM than all the sites sampled in this study. LS Sub-Site 1 had a mean OM of 73.785%±1.321 and LS Sub-Site 2 had a mean OM of 58.111%±1.650 for the entire soil sample. The mean OM for LS was 65.780%±1.272. The WK sub-sites were found to have much lower percentages of organic matter for the entire soil sample compared to the percentages found at LS. WK Sub-Site 1 had a mean OM of 27.097%±1.263 and WK Sub-Site 2 had a mean OM of 25.055%±0.847 for the entire soil sample. WK had a mean OM of 26.061%±0.759. The mean organic matter percentage for LS freshwater marsh is significantly greater than those of the WK freshwater marsh, see figure 3.1.

The top ten centimeters of each soil sample were analyzed separately to determine the OM (%) for each site. The top ten centimeters were looked at separately because of observed differences in OM (%) between the top ten centimeter and the whole soil sample. The mean OM for the top ten centimeters for LS Sub-Site 1 was 74.485%±2.889 and for LS Sub-Site 2 it was 69.341%±3.975. For WK Sub-Site 1, the mean OM for the top ten centimeters was 23.773%±1.225 and WK Sub-Site 2 was 21.780%±2.257. The mean OM for the top ten centimeters at LS was 71.913%±2.461 and at WK it was 22.777%±1.275. The mean OM (%) for the top ten centimeters of the soil samples taken at LS were significantly higher than those of WK (α=.05, P=.000004), see figure 3.1.

The freshwater marsh sampled at LS had high OM percentages and were the highest of all sites sampled in this study, but the WK sites did not follow this pattern. Organic soil is defined as soil with greater than 20% to 35% organic matter (Mitsch and Gosselink, 1993). The LS sites were clearly organic based on the percentages found in both sub-sites. This suggests that organic matter content alone cannot be used to determine increased hurricane susceptibility in freshwater marsh considering how significantly different the percentages were between LS and WK. Nyman et al. (1990) determined that the way fresh marsh receives its freshwater supply, has an effect on the amount of mineral and organic matter in the soil. This may explain why the WK sites had lower organic matter percentages than the LS sites. The WK sites have small tributaries of the Pearl River flowing adjacent to the sites and may be delivering mineral matter to the WK sites.

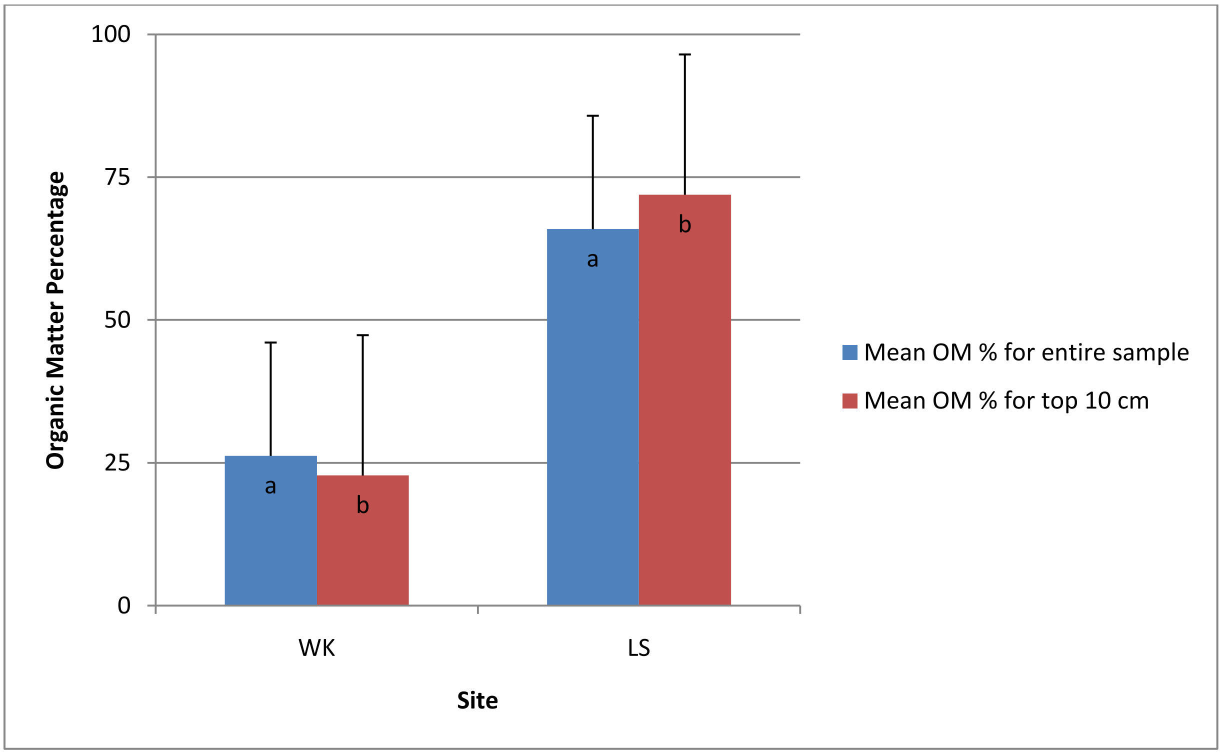


Figure 3.1: Mean Organic Matter Percentage for Entire Soil Sample (n=6, α=.05, P=0.000033) and the Mean Organic Matter Percentage for the top 10 cm of Soil Samples (n=6, α=.05, P=0.000004) for the Freshwater Marsh Sites. Different letters indicate significant differences in mean. Pooled data for sub-sites at LS and WK.

H-II: <u>Some restoration projects are creating marsh with high percentages of soil organic matter.</u>

There were two different types of restoration examined in this thesis project. The two types were the use of dredged material in marsh creation and hydrological restoration in an existing marsh. The Bayou LaBranche Restoration Project (BLB) employed the use of dredged material in marsh creation and in the Fritchie Marsh Restoration Project (FM) natural hydrology patterns were restored. Soil samples were taken at each site to analyze the amount of organic matter present in the soil. BLB had the lowest OM (%) of all the sites sampled for the entire study. The mean OM of the BLB Sub-Site 1 was 4.729%±0.525 and at BLB Sub-Site 2 it was 6.695%±0.806. For BLB, the mean OM (%) was 5.704±0.486. The mean OM for FM Sub-Site 1 was 39.203%±1.489, for FM Sub-Site 2, 36.274±1.340; and for FM Sub-Site 3, 42.633±1.665. The mean OM (%) at FM was 39.360%±.877. FM had significantly greater levels of organic matter in the soil than BLB (α=.05, P=0.0000000008), see figure 3.2.

The top ten centimeters of each soil sample were also analyzed to determine the OM (%) for each site. The mean OM for the top 10 cm of the BLB Sub-Site 1 was 8.413%±1.99 and at BLB Sub-Site 2 it was 14.064%±2.690. At BLB, the OM for the top 10 cm was 11.239%±1.726. At FM, the mean OM was for FM Sub-Site 1, 28.688%±1.988; FM Sub-Site 2, 29.625%±3.844; and FM Sub-Site 3, 30.058%±3.062. The overall mean OM at FM was 29.457%±1.728, see figure 3.2.

The results from BLB suggest that this restoration project is not creating marsh with a high percentage of organic matter in the soil. The data for FM suggests that restoration of a site's hydrology may cause higher percentages of organic matter in the soil. The data collected for the two types of restoration suggests that these two types of projects in particular are not creating marsh with extremely high amounts of organic matter in the soil. Although FM had significantly higher levels of OM in the soil than BLB, the mean percentages were significantly less than those found at the LS sites ($\alpha=0.05$, $P=0.0002$), see figure 3.3.

The mean OM (%) for the top 10 cm at BLB sites was slightly higher than the OM (%) for the entire soil sample. Several studies showed that over time, OM (%) increases in marsh created with dredged material (Lindau and Hossner, 1981; Patrick et al. 1984). The BLB project was completed on April 1, 1994 so there is a 16 year time span between the time of the project and the data collected for this thesis project. If organic matter increases over time in marsh created with dredged material, then it would be expected that the top layers of the soil samples to have higher percentages of organic matter compared to the whole sample. The analysis done by DNR in 1998 (Troutman, 1998) actually showed a decrease in organic matter percentages instead of the expected increase. This may be attributed to the short amount of time between the project start and the first round of monitoring. The 2002 data collected showed an increase in OM from approximately 5% to approximately 12% (Boshart, 2004). This is consistent with the results of the data collected for this thesis project. A natural function of marsh is vertical accretion and based on the results of this thesis project and Boshart (2004), the marsh seems to be vertically accreting on top of the dredged material. This might suggest that over time marsh soil may return to a more natural state or a state more similar to surrounding natural marsh soil in both soil composition and function.

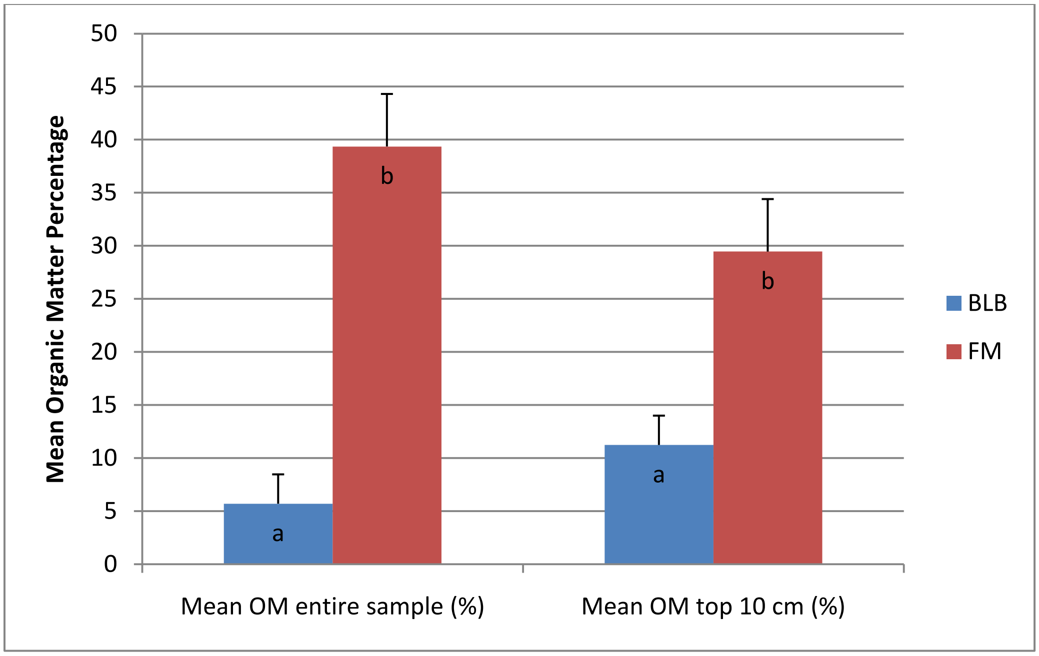


Figure 3.2: Mean Organic Matter Percentage for Entire Soil Sample (BLB n=6, FM n=9, P=0.0000000008) and the Mean Organic Matter Percentage for the top 10 cm of Soil Samples (BLB n=6, FM n=9, P=0.0002) for the Restoration Project Sites. Different letters indicate significant differences in mean. Pooled data for sub-sites at FM and BLB.

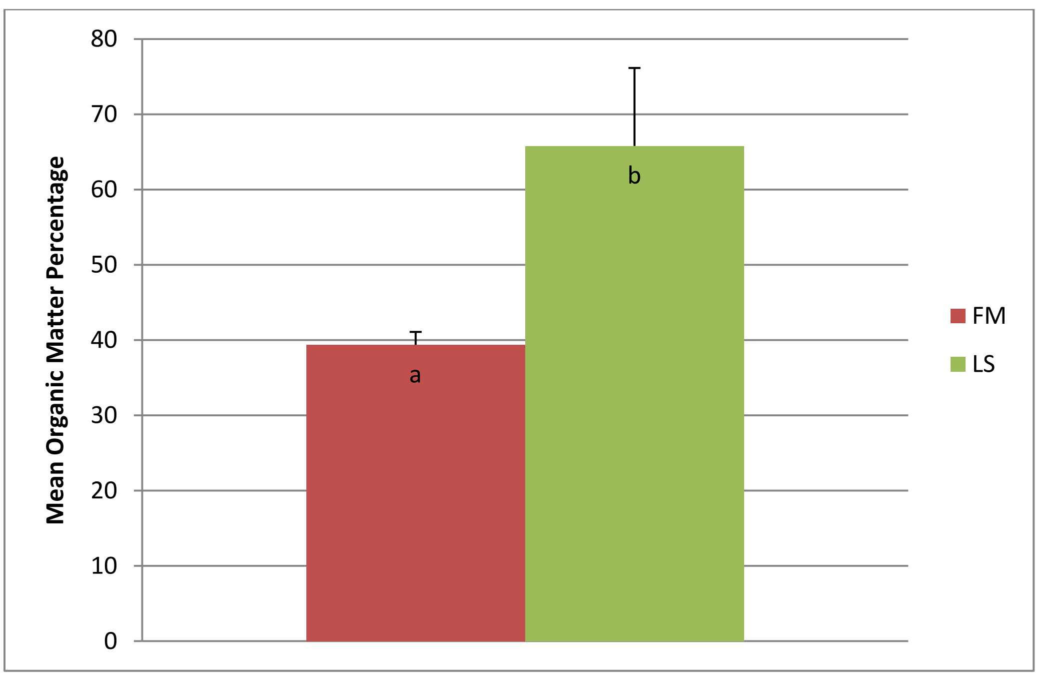


Figure 3.3: Mean Organic Matter Percentage for Entire Soil Sample (LS n=6, FM n=9, P=0.0002). Different letters indicate significant differences in mean. Pooled data for the sub-sites at FM and LS.

3.2 Buoyancy

Buoyancy is essentially a measure of weight and density. If an object has a low weight and is less dense than the liquid it is placed in, then that object will float. Buoyant force is equivalent to the weight of the water displaced by the object. Bulk density and sample weights will have an effect on the buoyancy of the object. Buoyant or floating marsh floats above the lower substrates and may be more susceptible to hurricane damage. Buoyant marsh is more easily shifted, deformed or destroyed because of low soil weights and a lack of connection to the underlying substrate which helps to anchor the marsh in place. Without this connection, the marsh can be lifted and transported by storm surge or hurricane force winds more easily. Several freshwater sites adjacent to marsh converted to open water during Hurricanes Katrina and Rita were examined to determine their buoyancy, weights, and bulk density. Restoration sites were also examined to determine these same properties to conclude if restoration projects were creating marsh potentially more susceptible to hurricane damage. By comparing the sensitive marsh, the marsh adjacent to the sites lost during Hurricanes Katrina and Rita, to different restoration projects, we can determine if similar characteristics are found between sites. If we can compile a range or set of values for certain characteristics i.e. buoyant force, bulk density, OM (%) of the type of marsh found in these adjacent sites, then for future restoration projects we can create a marsh soil type that is different. For example, if a certain range of OM (%) indicates a high possibility for buoyancy in late summer months, then restoration projects should try to create soil with, in this case, a lower range of OM (%) to reduce the possibility of buoyancy in late summer months.

H-III: <u>Freshwater marsh surrounding marsh converted to open water during Hurricanes Katrina and Rita is buoyant during late summer months.</u>

Buoyancy was calculated in the lab for samples taken from each site. The freshwater sites were not found to be buoyant based on the analysis in the lab. A low buoyant force means the samples had the highest potential to be buoyant because of low sample weights and low soil bulk density. Marsh soils with low weights and low bulk densities, depending on decomposition rates, may be buoyant at different times. So if the soil sampled during this thesis research was not found to be buoyant, but had a low weight and low bulk density and if decomposition rates are higher at another time then the site may become buoyant. The LS Sub-Site 2 was observed to be buoyant based on field observations. The marsh moved up and down considerably when walking and jumping on the surface. The LS sites also had some of the lowest buoyant forces of all sites sampled in this study. The LS samples displaced the smallest amounts of water in lab analysis. Sasser et al. (1996) described the type of floating marsh found at LS. The north and east shores of Lake Salvador have floating marsh dominated by *Sagittaria lancifolia*. The *Sagittaria* dominated floating marsh do not have the extensive fibrous root system that the *Panicum* dominated mats have which causes the root zone to be more easily disrupted. The mat buoyancy is highest during summer and fall and is lowest or non buoyant during winter and spring (Sasser et al. 1996). The description from Sasser et al. (1996) is consistent with what I found at the LS Sub-site 2. The floating site at LS Sub-site 2 was dominated by *Sagittaria lancifolia* had the lowest mean bulk density and lowest mean dry weights of all sites sampled in this study. LS Sub-Site 1 was dominated by *Panicum hemitomom* and was not observed to be buoyant in the field based on the same test I did at LS Sub-Site 2. The marsh surface at this site did not move up and down when jumped or walked upon. LS Sub-Site 1 had a mean buoyant force of 2.448N±0.163 and LS Sub-Site 2 had a mean buoyant force of 1.770N±0.092. The difference in mean buoyant force was found to be significant (α=0.05, P=0.001) between the two LS sites. This correlates to the observations of buoyancy at LS Sub-Site 2 and not at LS Sub-Site 1. LS had a mean buoyant force of 2.109N±0.122 and WK had a mean buoyant force of 2.889N±0.108. The mean buoyant force at LS was found to be significantly lower than those found at WK (α=0.05, P=0.000018). This is consistent with lower mean dry weights, mean bulk density and mean buoyant forces of the LS site compared to the WK site. Figures, 3.3 & 3.4, show the correlation between buoyant force and bulk density for all sites sampled.

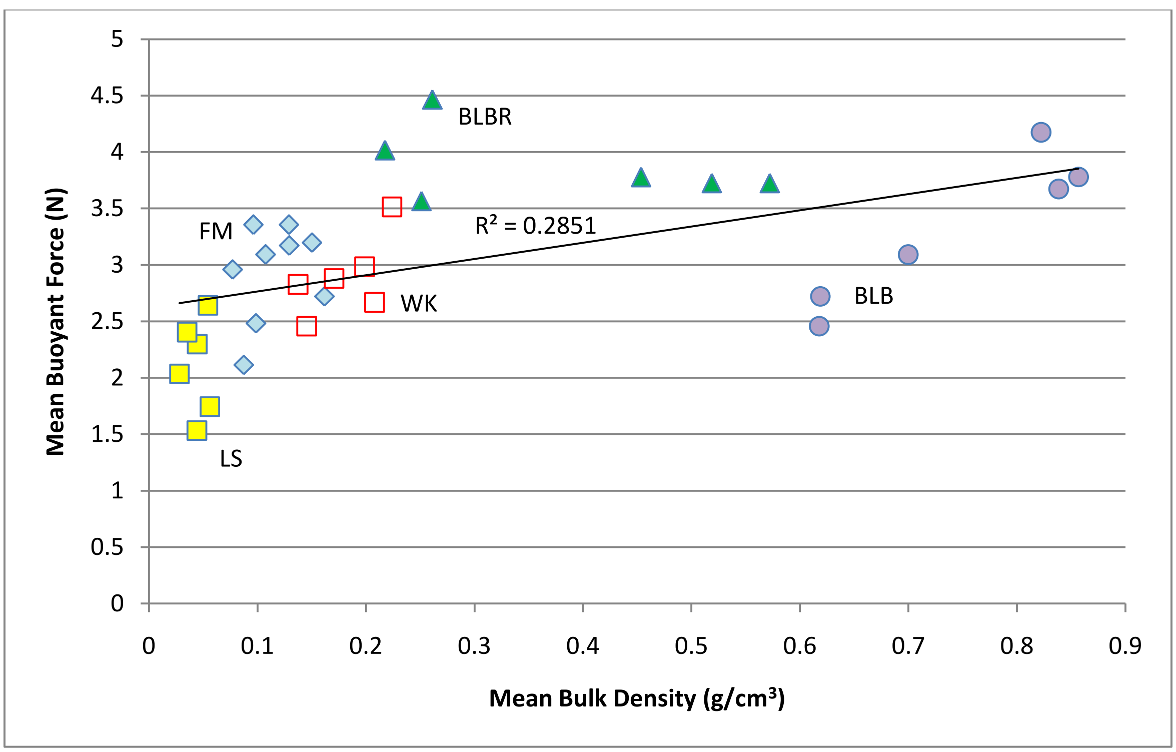


Figure 3.4: Mean buoyant force values versus mean bulk density values. Combined data set from LS, FM, WK, BLBR, and BLB. (n=33, r^2=0.285).

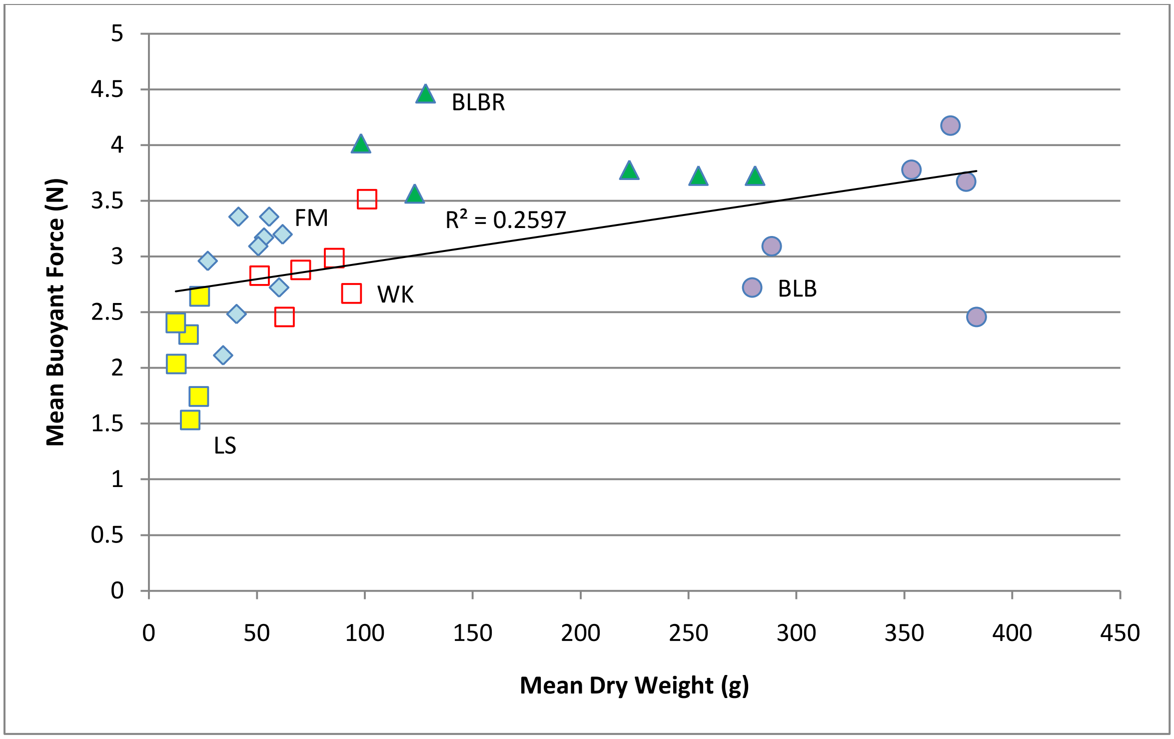


Figure 3.5: Mean buoyant force values versus mean dry weight values. Combined data set from LS, FM, WK, BLBR, and BLB. (n=33, r^2=0.260).

H-IV: <u>Some restoration projects are creating marsh that is buoyant in late summer months.</u>

Restoration projects were not found to be buoyant in both lab analysis and field observations. BLB had the highest mean buoyant forces of all the sites sampled. A high buoyant force means that this site had soil samples that did not float and have the least potential for buoyancy. The mean buoyant force at BLB was 3.316N±0.154 and the mean buoyant force at FM was 2.939N±.115. The mean buoyant force at BLB was significantly higher than the mean buoyant force at FM (α=0.05, P=0.0287), see figure 3.6. The mean buoyant force at LS was significantly lower than BLB (α=0.05, P=0.0000003621) and LS was also significantly lower than FM (α=0.05, P=0.00000007096).

BLB had a mean bulk density of 0.742g/cm^3±0.045. BLB had the highest mean bulk densities of all sites which were consistent with BLB having the highest mean buoyant forces as well, see Figure 3.7. FM had a mean bulk density of 0.115 g/cm^3±0.010. The mean bulk density at BLB was significantly greater than at FM (α=0.05, P=0.00001949). LS had a mean bulk density of 0.044 g/cm^3±0.004. When compared to LS, FM had a bulk density that was significantly greater than LS (α=0.05, P=0.00001597).

When compared to the LS sites, the restoration sites at FM and BLB had significantly higher mean bulk density measurements than the sites at LS. FM and BLB also had significantly higher buoyant force values than the LS sites. The results indicate that the particular restoration projects examined are not creating marsh that is buoyant in late summer months. Due to the low percentages of OM especially at BLB, I do not think that FM or BLB will have marsh that is buoyant in late summer months. Even with the OM (%) increase over time at the BLB sites, the amount of OM in the soil still remains low. Also, the BLBR sites had mean OM of less than 20% to 35% which classifies the soil here as mineral (Mitch and Gosselink, 1993) with high soil bulk density as well. The hydrologic restoration at FM will likely increase the amount of mineral matter being deposited in the marsh and with that, an increase in bulk density at these sites. The analysis on OM showed that the mean for the top ten cm of the sample at the FM sites was lower than for the entire sample.

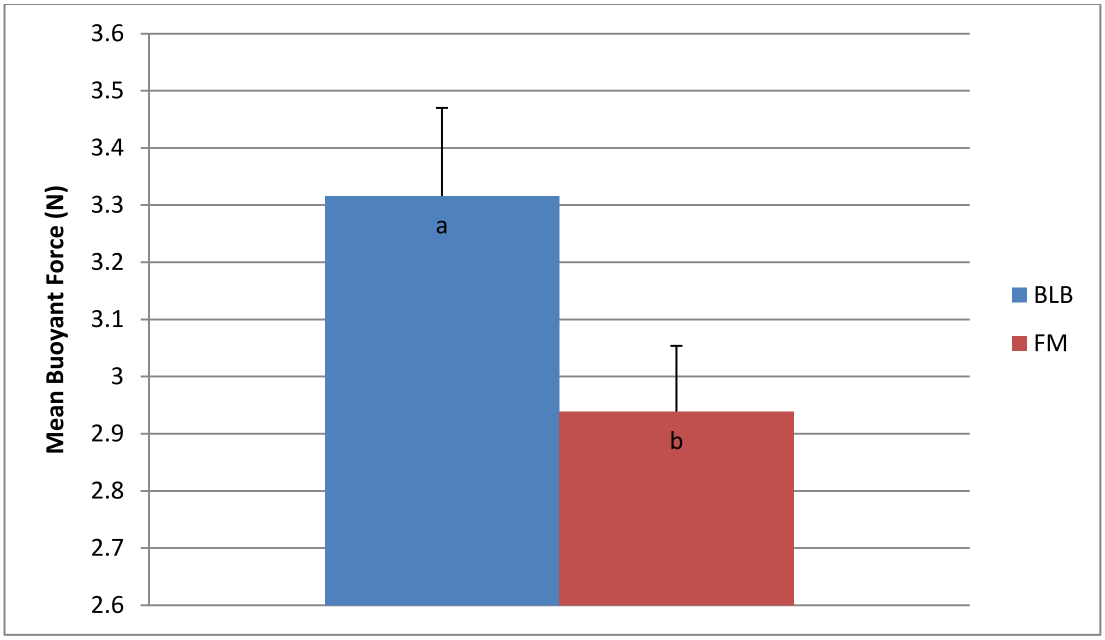


Figure 3.6: Mean buoyant force for BLB and FM. (BLB, n=18; FM, n=27, P=0.0287). Different letters indicate significant difference in means.

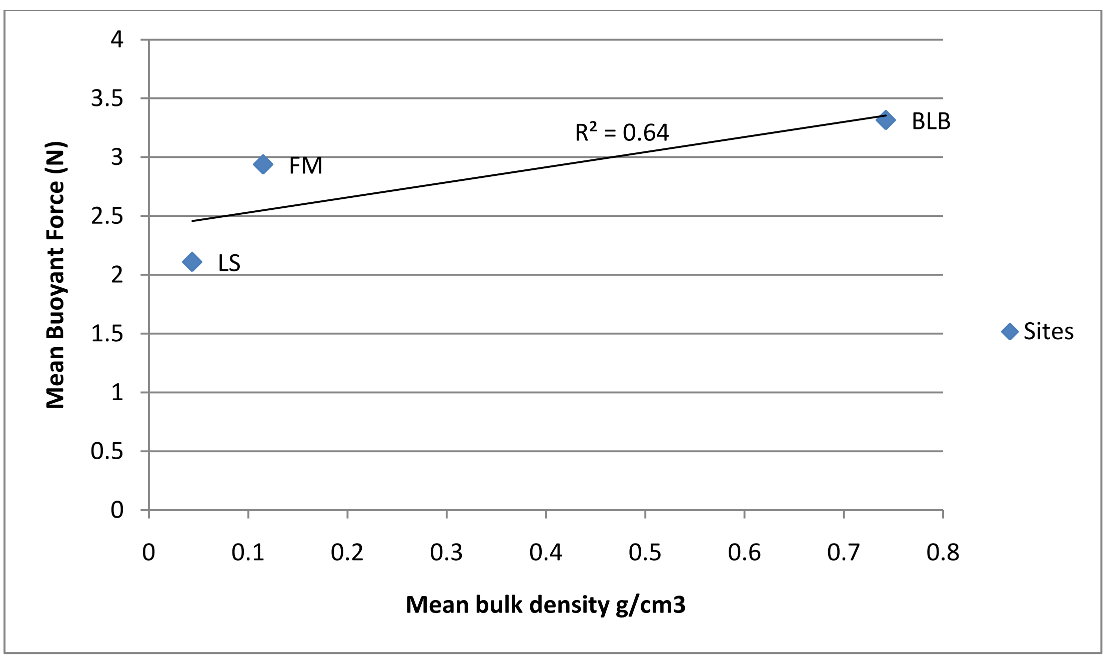


Figure 3.7: Mean bulk density versus mean buoyant force for LS, BLB, and FM. (n=21, r^2=0.64).

H-V: The marsh soils with the highest organic matter percentages are the most buoyant.

A low buoyant force indicates that a small amount of water was displaced by an object. Buoyancy was tested in the laboratory to determine which sites were experiencing periods of buoyancy in late summer months. The buoyant sites were expected to have the highest amounts of organic matter in the soil. Hatton (1983) found that bulk density was dependent on the amount mineral sediment in the soil. The freshwater sites examined in Hatton et al. (1983) were found to have the highest percentages of organic matter in the soil, the lowest percentages of mineral sediment and the lowest bulk densities of all sites sampled.

Based on the analysis for this thesis project, none of the sites appeared to be buoyant. In field observations, as state previously, the LS Sub-site 2 was in fact buoyant and also has the highest amounts of organic matter in the soil. LS Sub-site 2 had a mean buoyant force of 1.77N±0.092 and a mean OM of 69.341%±3.975. Overall, LS had the lowest mean buoyant force, 2.109N±0.122 and the highest mean OM, 65.780%±1.272 of all sites sampled, see figure 3.8. Theoretically, the lightest samples should displace the smallest amount of water which was observed in the lab. LS Sub-site 2 had a mean bulk density of 0.043 g/cm^3±0.008 and was the lowest of all sites sampled. Overall, LS had a mean bulk density of 0.044 g/cm^3±0.004 and was the lowest of all sites sampled, see figure 3.9.

The mean buoyant force, mean OM (%) and mean bulk density were compared for the WK sites and FM to determine if there was a significant difference between the two sites. The sites produced similar results in weights, bulk densities, and OM (%) even though the WK sites are fresh marsh and the FM sites are brackish marsh. This could be attributed to the hydrological restoration project at FM. The mean buoyant force at WK, 2.889N±0.108, was not significantly higher than the mean buoyant force of 2.939N±0.115 at FM, see figure 3.8. (FM n=27, WK n=18, P=0.082). The mean bulk density of 0.181 g/cm^3±0.014 at WK was found to be significantly higher than the mean bulk density of 0.115 g/cm^3±0.01 at FM. (FM n=9, WK n=6, P=0.002). Mean OM (%) was significantly lower at WK than at FM (FM=9, WK=6, P=0.0000199).

As hypothesized, the sites with the highest organic matter had the lowest buoyant forces. This is also consistent with LS having the lowest mean bulk density measurements and lowest sample weights. Several studies including, Barras (2005), Guntenspergen et al. (1995) and Jackson et al. (1995), found that the range of OM for floating fresh marsh that had significant loss during hurricane events was 35% to 75%. This is similar to the results of this thesis project. The LS sites especially fell well within that range. LS sub-site 2 was the site that I determined to be buoyant based on my field observations, as previously stated. This site was not buoyant when I performed my analysis in the lab. The reason for this inconsistency, I believe, is due to the experimental design. The buoyant mat of floating marsh is held together by the roots of the plants. When I took soil samples, some of the roots were cut and caused some of the mat to disconnect from each other and sink to the bottom of the graduated cylinder. The piece that remained intact floated at the top of the graduated cylinder. The part that sunk added to the amount of water displaced by the sample and caused the results to show that the sample was not buoyant. I think larger sections of marsh would need to be taken in order to maintain the root integrity of the floating mat layer. Also, a larger water surface area might help to disperse some of the weight of the larger samples and give a more accurate buoyancy result. There are only a few studies that measure buoyancy of marsh directly.

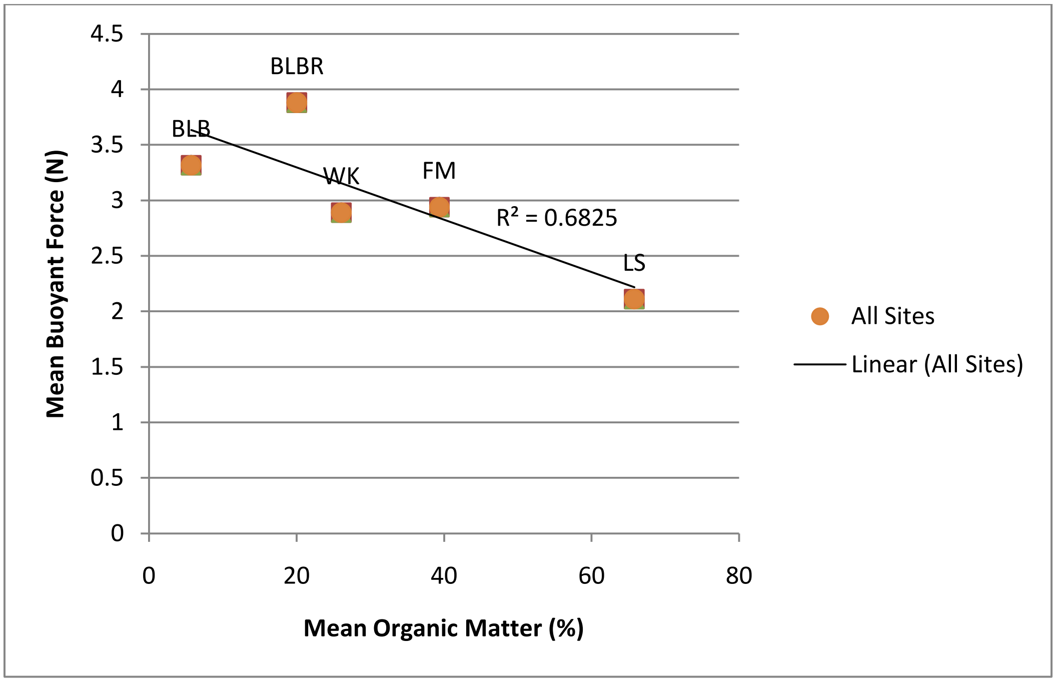


Figure 3.8: Mean Organic Matter versus mean buoyant force for each site. (r^2=0.682).

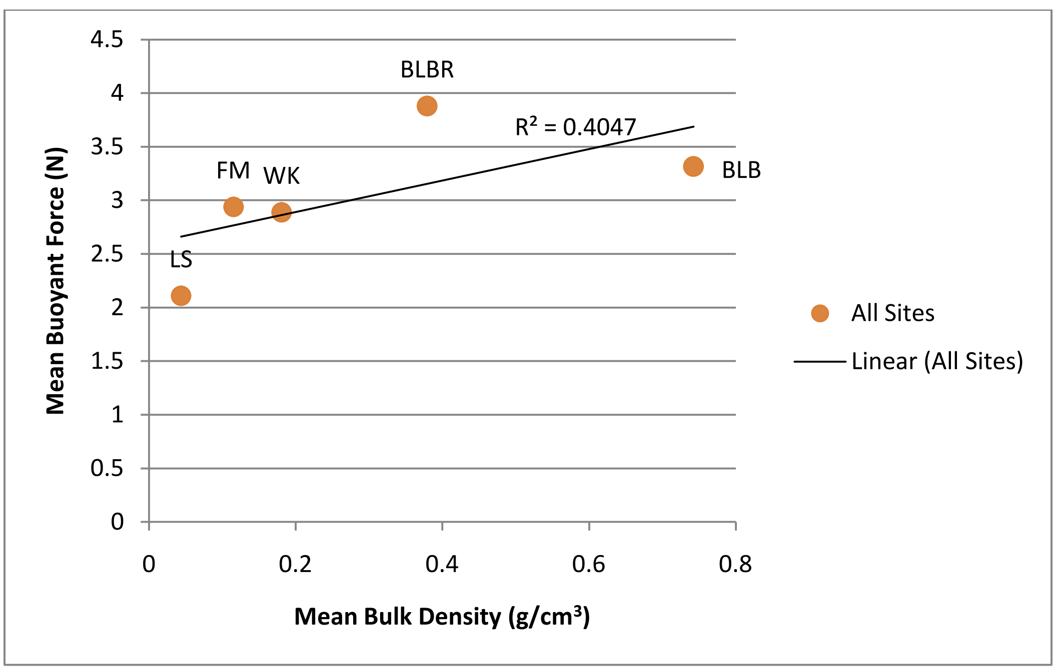


Figure 3.9: Mean buoyant force versus Mean Bulk Density for each site. (r^2=0.405).

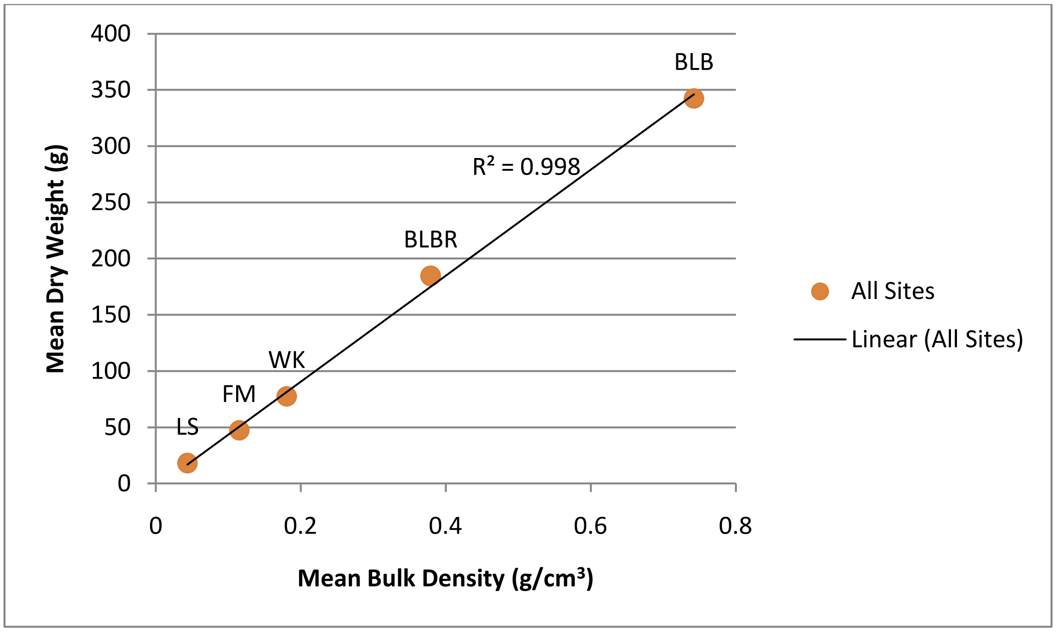


Figure 3.10: Mean dry weight versus mean bulk density for each site. (r^2=0.998).

H-VI: Some restoration projects are creating soils significantly different from their corresponding reference site soils.

Marsh restoration projects attempt to create new marsh or restore marsh that has been damaged. Several different types of projects exist to achieve these goals. The BLB site is marsh created through the use of dredged material. The goal is to determine if the marsh created with this type of project is similar to the marsh found in its corresponding reference site. The OM (%), bulk density, and buoyant force of the samples at the BLB site were compared to those in the corresponding reference site at BLBR. The mean OM for BLB, 5.704%±0.486, and BLBR, 20.030%±0.860 were found to be significantly different (n=6, P=0.007). The mean OM for the top ten cm at BLB was 5.704%±0.486 and at BLBR was 24.472%±1.706. The mean OM % for the top ten cm for BLB and BLBR were also found to be significantly different (n=6, P=0.01), see figure 3.12. The mean bulk density at BLB was 0.742 g/cm^3±0.045 and at BLBR was 0.379 g/cm^3±0.063. There was a significant difference in mean bulk density between the BLB and BLBR Sites (n=6, P=0.001), see figure 3.11. The mean buoyant force for each site was compared as well and was found to be significantly different between the sites (n=18, p=0.004). The mean buoyant force at BLB was 3.316N± 0.045 and at BLBR it was 3.88N±0.093, see figure 3.11. Dominant plant species at BLB was *Scirpus americanus* and *Spartina alterniflora* and at BLBR dominant plant species was *Spartina patens* and *Spartina alterniflora*.

Based on field observations and data collected, the BLB and BLBR were found to be significantly different in every characteristic that was analyzed. The use of dredged material in this particular project seems to be creating marsh that is significantly different from the corresponding reference site. Just because the restoration site is different than its corresponding reference site does not mean the restoration project did not create viable, healthy, sustainable marsh. Over 16 years has passed since the BLB project was completed and the marsh is still intact. According to the map created by Barras (2005), very little marsh, if any, was loss during Hurricanes Katrina and Rita in the project area. Based on the analysis of the top ten cm, the amount of OM in the soil seems to be increasing as well which indicates that the marsh is capable of building upon the dredged material. Is it better to restore marsh even though it is different than the surrounding natural marsh or not have any marsh in place at all? If the restored marsh is in place, with further research we can determine how to achieve the functions and characteristics of natural marsh. If no marsh exists, then we have nothing to work with even if it is different from the surrounding natural marsh.

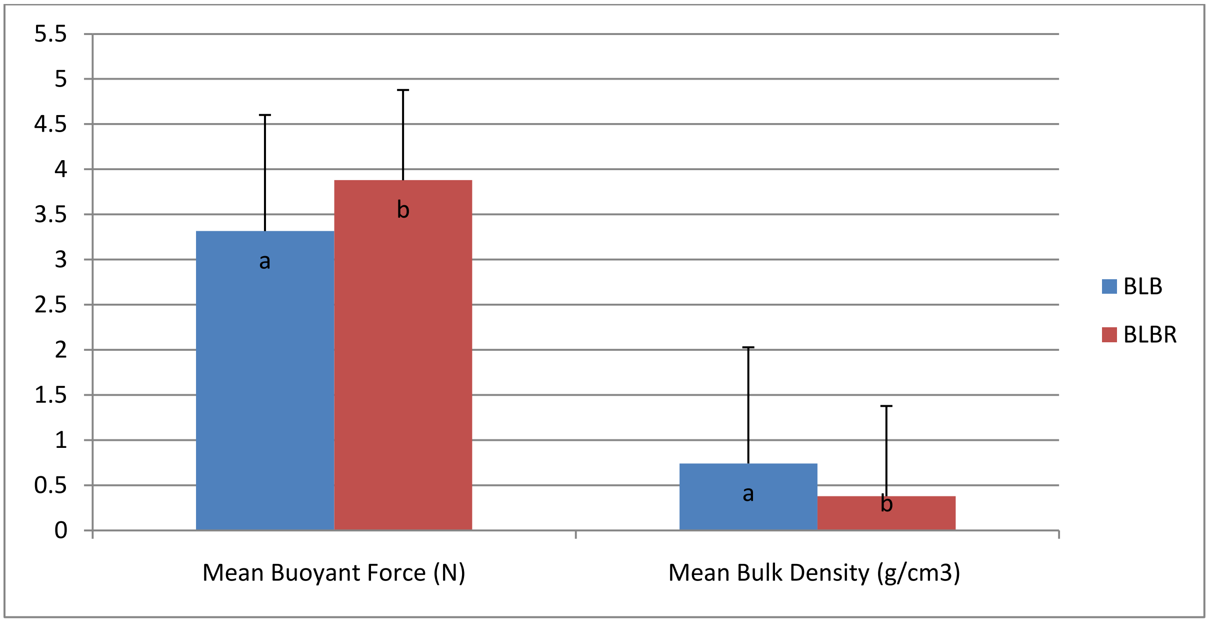


Figure 3.11: Mean buoyant force (n=18, P= 0.004) and mean bulk density (n=6, P=0.001) for BLB and BLBR. Different letters indicate significant differences in means.

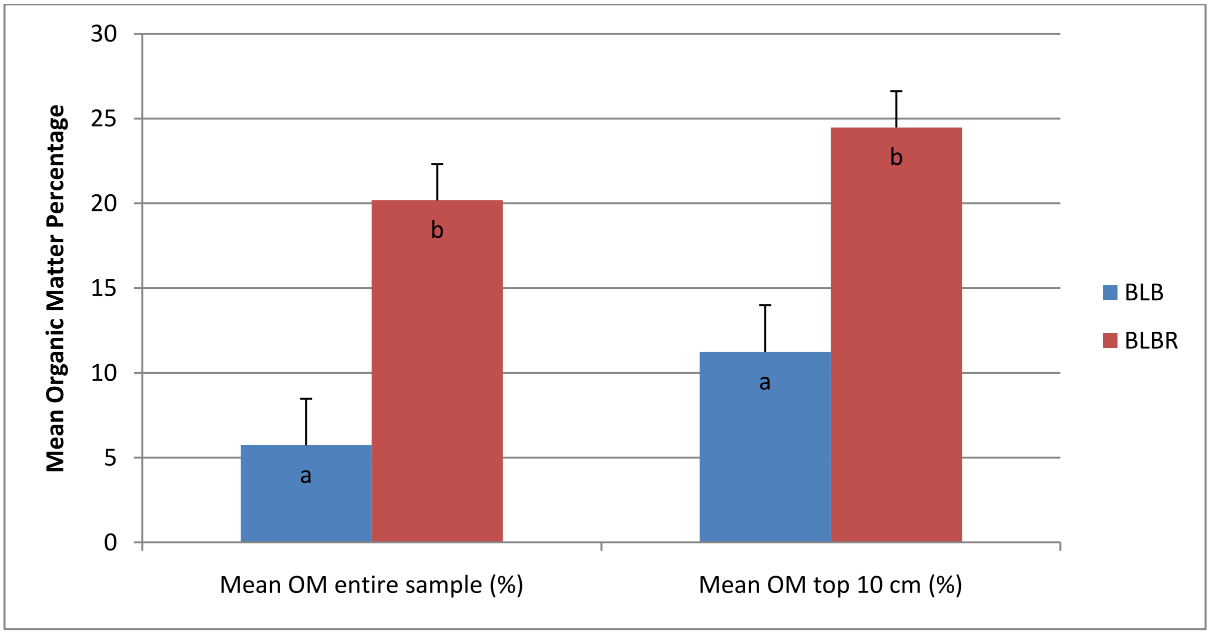


Figure 3.12: Mean Organic Matter Percentage for Entire Soil Sample (n=6, P=0.007) and the Mean Organic Matter Percentage for the top 10 cm of Soil Samples (n=6, P=0.01) for BLB and BLBR. Different letters indicate significant differences in mean.

H-VII: Marsh soils with the highest organic matter content and highest buoyancy were found in the freshwater marsh sites adjacent to those sites that experienced loss during Hurricanes Katrina and Rita.

Freshwater sites adjacent to marsh that were lost during hurricanes Katrina and Rita were chosen near Lake Salvador and also near the town of White Kitchen. To test this hypothesis, the organic matter in the soil was calculated using the LOI technique and experiments on buoyancy were performed in the lab as well. As previously stated, based on field observations, the LS Sub-site 2 was buoyant. The LS Sub-site 2 also had the highest percentage of organic matter in the soil. Buoyant force measurements were the lowest at this sub-site as well, see table 3.1. The low buoyant force indicates the highest potential of buoyancy which is consistent with the samples having the lowest bulk densities and highest organic matter percentages. These results are also consistent with Sasser et al. (1996), Gaudet (1977), Sasser (1994), and Swarzenski (2008) studies describing the floatant or buoyant marsh as having a high percentage of organic matter in the soil and low bulk densities. The WK site did not have some of the highest percentages of organic matter and did not have some of the lowest buoyant forces. This site is not consistent with the hypothesized results. The loss at WK can be attributed to its location. The track for Hurricane Katrina passed extremely close to the WK sites. Hurricane winds and storm surge is the probable cause of loss at these sites and not buoyancy. The WK sites felt the brunt of the storm due to its proximity to the eye of the storm. These sites would have experienced some of the strongest winds and wave action.

Site	OM (%)	OM top 10 cm (%)	Buoyant Force (N)	Bulk Density (g/cm^3)
LS	65.90±3.89	71.91±3.86	2.10±0.12	.04±0.00
WK	26.20±1.18	22.77±1.74	2.88±0.10	.18±0.01
FM	39.39±1.82	29.45±1.33	2.93 ±0.11	.11±0.01
BLB	5.73±0.97	11.24±2.65	3.31±0.15	.75±0.05
BLBR	20.17±3.52	24.47±3.45	3.88±0.09	.37±0.06

Table 3.1: Mean values for LS, WK, FM, BLB, BLBR sites. (Mean ± 1 Std. error). Pooled sub-site data.

H-VIII: <u>Dominant plant species is a good indicator of marsh soil buoyancy and organic matter content.</u>

If you could determine buoyancy of marsh visually, dominant plant species and plant community would be excellent indicators to use. Data was collected on dominant plant species and species composition for each site. Species abundance and percent coverage were also documented. Sasser et al. (1996) described several different types of floating marsh found in Southeast Louisiana: the thick mat *Panicum hemitomom* floating marsh, the thick mat *Sagittaria lancifolia* floating marsh and the thin mat *Eleocharis parvula* and *Eleocharis baldwinii* floating marsh. These three types differ in dominant species but also in mat thickness and substrate characteristics.

LS sub-site 2 was dominated by *Sagittaria lancifolia* and had the same characteristics described by Sasser et al. (1996). The marsh surface was soft, difficult to walk on and broke apart easily. The core samples were easy to extract because the root system below was not extensive. For each plot, three of the five locations were sampled to determine OM (%) and dominant plant species was noted for all five locations. Figure 3.13 shows the relationship between the dominant plant species and OM (%) for each plot. OM (%) did not deviate far from the mean for any plant species except for the *Panicum* dominated plots. LS and WK both had plots dominated by *Panicum hemitomom* which is why OM (%) deviates from the mean. The

WK sites had much lower OM (%) than the LS sites. Although the sites at WK are fresh, they are probably receiving more mineral matter input from the Pearl River tributaries and that caused the OM (%) to be much lower at these sites.

Based on the results of this thesis study, dominant plant species seems to be a good indicator of OM (%) of the marsh soil. There are circumstances where it might be misleading to determine OM (%) on dominant species alone. Taking soil samples for analysis would be beneficial in case there is some anomaly at a particular site.

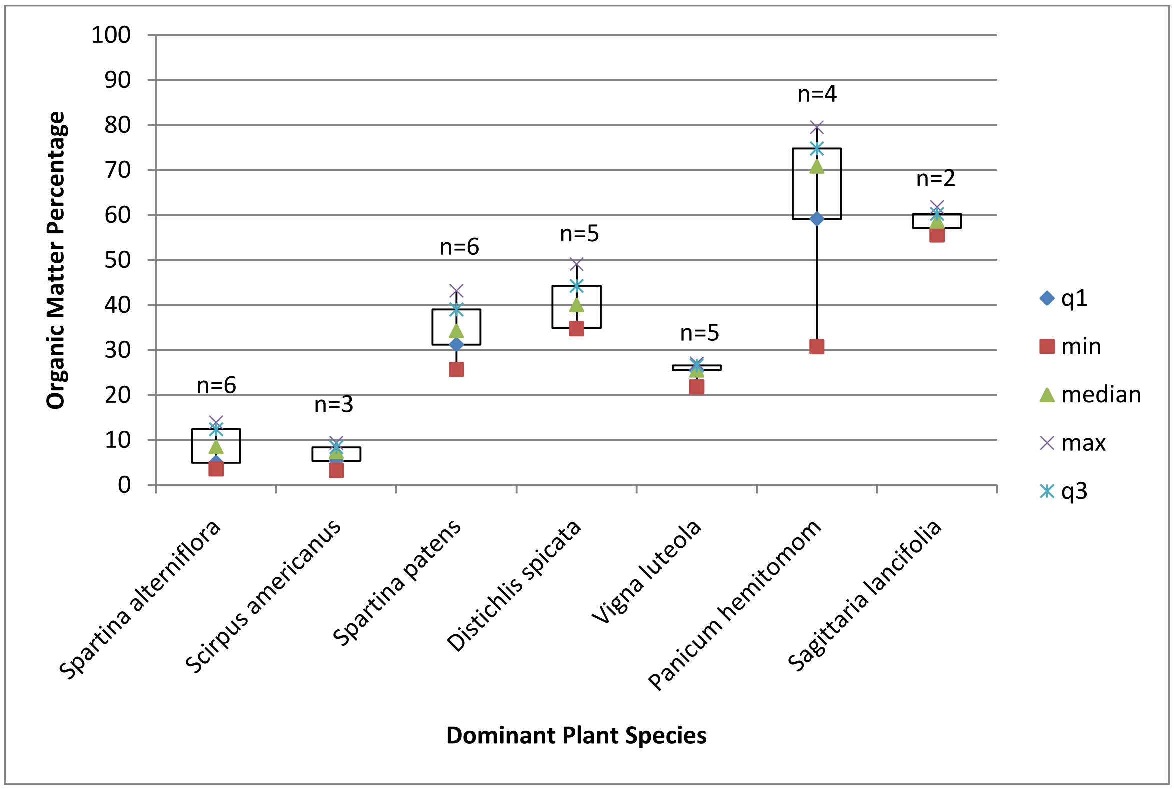


Figure 3.13: Dominant Plant Species and Mean Organic Matter Percentage for Plots. Pooled data sets for plots.

Figure 3.14 shows the relationship between dominant plant species and buoyancy of marsh. Based on the results, it seems that dominant plant species may be used to help identify buoyancy of a marsh. Excluding *Spartina patens* and *Distichilis spicata*, the results for the other types are centered on the median fairly evenly. The data is skewed for both *Spartina patens* and *Distichilis spicata*. This may be due to errors in the buoyancy testing.

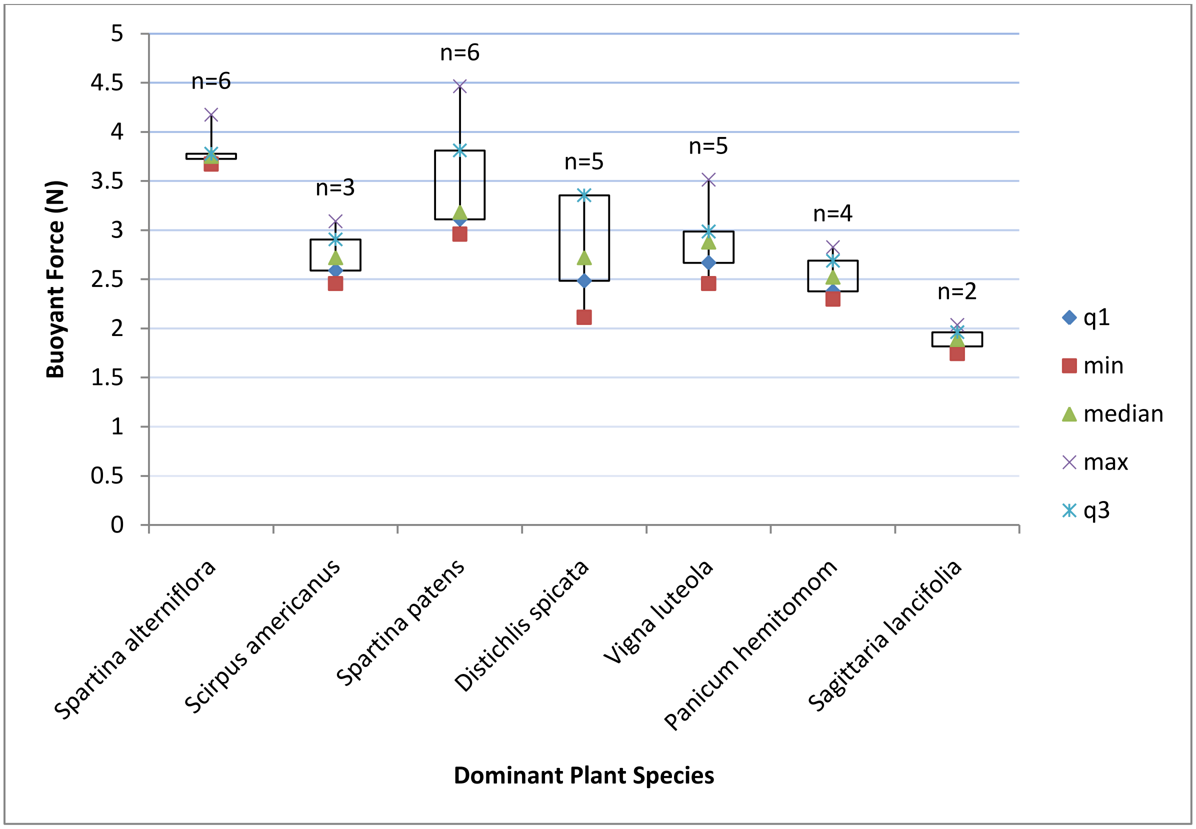


Figure 3.14: Dominant Plant Species and Buoyant Force for Plots. Pooled data sets for plots.

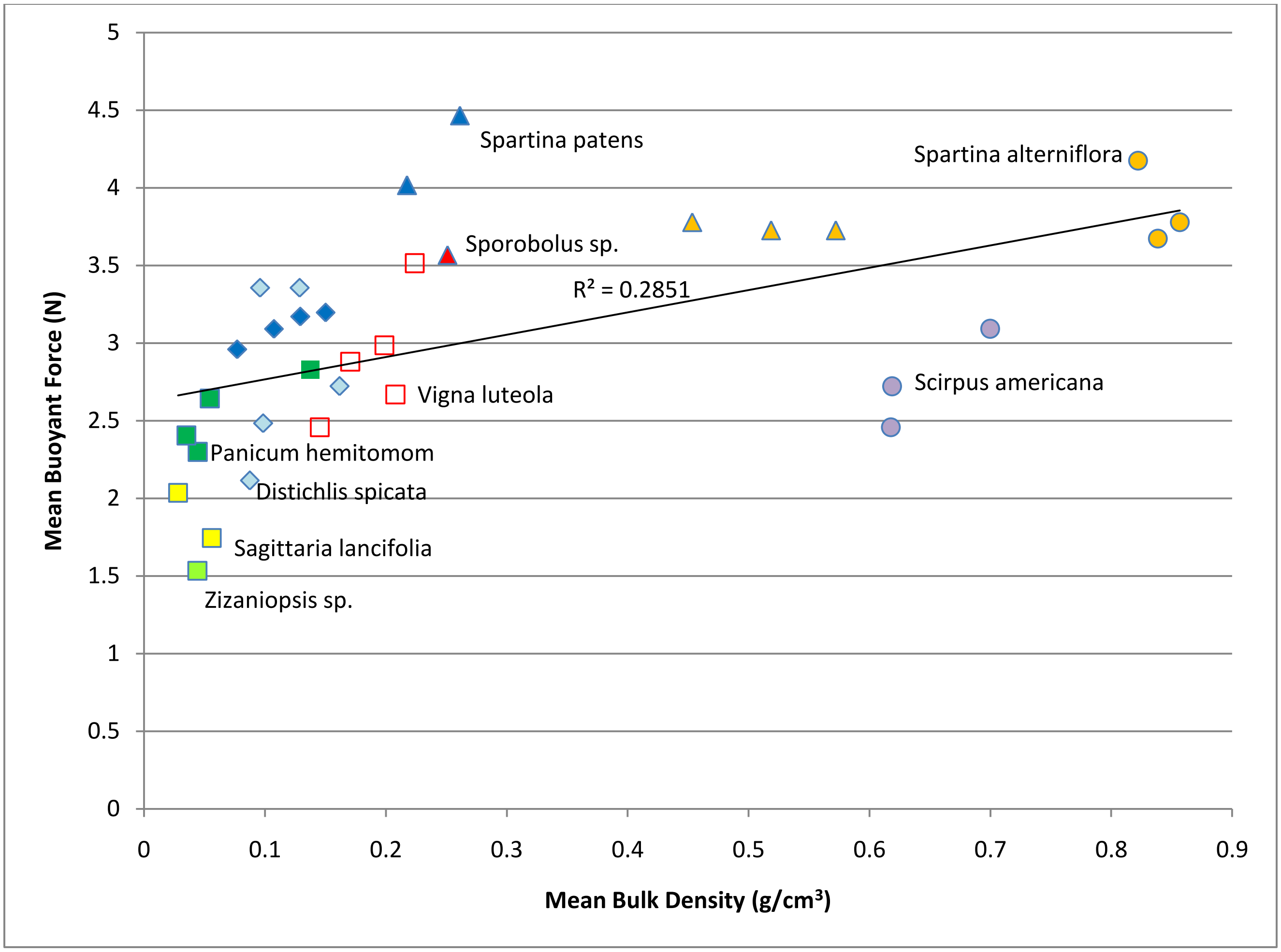


Figure 3.15: Mean Buoyant Force and Mean Bulk Density for Dominant Plant Species. Different colors indicate same dominant plant species.

3.3 Critiques and Additional Research

As stated previously, I think there are ways the buoyancy experiment could be improved. Larger samples placed in containers with a larger water surface area might produce a more accurate buoyancy measurement. The samples extracted with the corer had roots cut and cause some of the sample to break apart. This possibly caused some samples to sink and skew the buoyancy measurements for the samples as well.

There are several options for expanding the research started with this study. I think a seasonal measurement of buoyancy would give additional information on the seasonal changes at the sites studied. Also, analyzing other restoration projects such as freshwater diversions may find that certain types of restoration projects are creating buoyant marsh soils.

Chapter Four: Conclusions

4.1 Buoyancy

Buoyant marsh experiences greater damage during hurricane events than other marsh types. The sites in this thesis project with the highest amounts of organic matter had the lowest buoyant forces and lowest bulk densities, these sites were the ones adjacent to those that experienced land loss during Hurricanes Katrina and Rita at the LS sites. The results suggest that buoyancy can be used to determine, in some instances, marsh susceptibility at a particular location. The use of dredged material at BLB and the hydrological restoration at FM did not seem to create marsh that has a high potential for buoyancy and therefore, may not be more susceptible to hurricane damage particularly in late summer months.

Louisiana experiences marsh loss every year and hurricanes are responsible for some of the marsh loss. The various marsh types found in Louisiana respond differently to hurricane damage. Differences in plant communities, organic matter percentages, bulk densities and buoyancy are responsible for these different types of responses. Some marsh types may be more susceptible than others. The goal of restoration projects should be to not only create or restore marsh, but to ensure that the marsh is sustainable for the long term. The goal of this project was to determine if buoyancy was a key factor in marsh susceptibility to hurricanes. The results of this thesis project showed that buoyancy may be a way to determine marsh susceptibility. Scientists can create more sustainable marsh by possibly adding mineral matter to the soil. Also, scientists can make sure plants that are associated with heavier marsh types are present in some of these susceptible marshes. If environmental scientists can determine the characteristics of these sensitive buoyant marsh types, then the goal of restoration projects should be to create marsh that differs from those more susceptible marsh types.

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