A MULTI-PROXY APPROACH TO IDENTIFYING MARINE OVERWASH SEDIMENTATION AND TERRESTRIAL FLOOD SEDIMENTATION IN A COASTAL LAKE IN SOUTHEASTERN TEXAS

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This research project focuses on using a multiproxy approach to discriminate between overwash and non-hurricane marsh sediments within the bed of a coastal lake. Three marsh cores were collected in an area of McFaddin National Wildlife Refuge just south of Clam Lake that are known to contain 4 hurricane overwash deposits, Ike, Rita, Carla, and Audrey. LOI and XRF analysis were used to determine the signature of the hurricane overwash layers. 3 more cores were collected from Clam Lake where there are no visible sand layers. The elemental signature of the overwash layers found in the marsh cores was used to run a hierarchical cluster analysis on the lake cores. This was able to determine the effectiveness of XRF's ability to distinguish between hurricane overwash and marsh sediments. The combination of cluster analysis, LOI, and XRF can tentatively identify hurricane overwash deposits in a coastal lake, however, it is more successful in the marsh cores. Results in the lake cores are somewhat inconsistent and uncertain, possibly because there may have not been enough overwash deposits to identity or that the XRF analysis needs more distinct sand layers to distinguish between overwash and marsh.

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CHAPTER 1

INTRODUCTION

1.1 Background

The Gulf of Mexico's coastal plain contains 41 percent of the national inventory of coastal wetlands and 80 percent of the nation's wetland loss (Turner, 1997). The loss of wetlands to open water has gained considerable attention, especially with concern to sea level rise due to global warming. Turner (1997) states that between 1955 and 1978, the rate of northern Gulf of Mexico marsh loss was 127 km2 per year. This rate is the equivalent to the area of Rhode Island every 21 years. The Intergovernmental Panel on Climate Change (2019) suggest the global mean sea level (GMSL) will rise between 0.43m and 0.84m by 2100. Blum and Roberts (2009) estimate that an additional 10,000-13,500 km2 will be submerged in the absence of sediment input.

Coastal wetlands provide multiple regulating services. Wetlands' structure attenuates waves and stabilizes sediment. In return, these functions provide coastal protection from storms, flood protection, and erosion control. Coastal wetlands' plants directly affect the physical processes on shorelines. For example, aboveground plant stems and leaves are in direct contact with seawater and sediment being brought in by storm surge and flooding. The plant stems and leaves increase turbulence, slow water velocity, and increase deposition (Gedan, Kirwan, Wolanski, Barbier,& Silliman, 2010). The Gulf and Atlantic coasts are subject to frequent hurricanes, bringing flooding and high winds that can cause significant damage to infrastructure (Purcell, Khanal, Straka, & Willis, 2020). Coastal wetlands provide protection for local populations and structures by acting as a barrier or buffer to storm surge and waves from hurricanes.

Multiple factors contribute to wetlands changes. These factors can control wetland stability, ecosystem function, and surface elevation (Cahoon, 2006). Research in Louisiana showed that sediment starvation, or decrease in sediment supply, is the main cause of land loss (Turner (1997). Sedimentation contributes to wetland surface elevation and helps counter elevation loss due to sea level rise (Williams & Liu, 2019). It is especially important to understand sources, pathways, and rates of sedimentation in order to maintain coastal wetlands, as well as identify and regulate human activities that inhibit wetlands' natural ability to adapt to changing environmental conditions.

1.2 Impacts of Hurricanes on Coastal Wetlands

Coastal wetlands depend on biophysical processes to maintain surface elevations relative to sea-level (McKee & Cherry, 2009). They are formed through intermittent transport and deposition of marine and riverine sediments (Conner, Day & Randall, 1989). High energy events, such as hurricanes, can activate processes including the formation of washover fans, the re- distribution of sediments, and the delivery of new sediments. Hurricanes are strong tropical storms that are defined by wind speed. The amount of storm surge sediment that is delivered to an area is dependent upon a hurricane's ability to generate a storm surge and waves with enough energy to transport sediments. Factors that affect storm surge are the distance from the site to the eye of the storm, position in relation to the hurricane, and the hurricane's magnitude. Also, the availability of sediment and the presence of local topographic and/or hard structures (sea walls, dykes) that have the ability to enhance or diminish storm surge, will play a role in the amount of sediment delivered (Williams & Flanagan, 2009).

Recent research studies have attempted to quantify the contribution hurricanes make to surface accretion of coastal wetlands, with the hope of encouraging coastal management strategies that promote hurricane-induced sedimentation. Williams and Flanagan (2009) studied the contribution of Hurricane Rita's storm surge deposition to long-term sedimentation in coastal marshes and woodlands in Cameron Parish, Louisiana. Hurricane Rita's storm surge sedimentation extended about 400-500m inland and was up to 50cm thick (Williams & Flanagan, 2009). The thickness of Hurricane Rita's storm surge deposit is the equivalent of a decade to over a century's worth of non-storm-surge sedimentation (Williams & Flanagan, 2009.) The long term impact of sediments derived from hurricanes has been difficult to quantify over large areas. However, Tweel and Turner (2014) quantify the long-term contribution to soil inorganic matter for three hurricanes, Rita, Katrina, and Gustav, across coastal Louisiana. They found that for the Chenier plain and the 80% of the Louisiana coast that consists of abandoned delta lobes, hurricane storm surge sedimentation is the leading source of inorganic sediment (Tweel & Turner, 2014). By using hurricane activity from the past 84 years to estimate hurricane activity throughout the Holocene, Cahoon (2006) estimated that 40,000 tropical cyclones have made landfall in the Gulf of Mexico region during the Holocene. This suggests that hurricane-derived sedimentation is a major source of sediment input for these coastal regions.

1.3 Characterizations of Hurricane Sediments

Although recent studies have made significant progress in identifying hurricane washover sediments in coastal marshes, little work has been done to identify and differentiate marine overwash and terrestrial flood deposits in coastal lakes. A common approach in coastal geomorphological and paleotempestology studies is to identify and date hurricane layers within lake beds, marshes, and lagoons (Williams, 2010). This approach is based on the idea that a hurricane storm surge will transport and deposit allochthonous material onto the finer, more organic-rich, low-energy marsh sediments, leaving an anomalous and distinctive sand layer. There are multiple established proxies used for identifying hurricane layers within a sediment core: grain size analysis, organic matter analysis, and micropaleontological analysis. However, over the past decade, a number of geochemical based proxies have also been introduced (Oliva, Peros, & Viau, 2017).

Grain size analysis can show changes in energy transport conditions at a site. Coastal marshes and lakes are low energy environments and consist of fine organic rich sediments. When a coarser sediment layer is present, it is an indication of an energy shift in the environment (Oliva, Peros, & Viau, 2017). There are quantitative and qualitative techniques to generate grain size data. The latter utilizing descriptions of visible sand layers thought to be attributed to hurricanes. Loss-on-ignition (LOI) can be used to estimate the organic matter content, siliciclastic content, and total carbonate within a sediment sample. The use of LOI as a proxy to identify hurricane layers is based on the assumption that the overwash layer will have more sand and carbonates and less organic content then the sediment regularly deposited on marshes (Oliva, Peros, & Viau, 2017). Yao, Liu, and Ryu (2018) describe hurricane Rita and Ike storm deposits on the southwestern Louisiana coast, from a 30cm-long monolith, as two distinct light-colored calcareous sediment layers within brown clay. Both storm deposits consist of a small amount of quartz and gravel, some foraminifera, and shell fragments. The LOI data reveals that the brown clay has relatively high water (>50%) and organic matter (>10%) contents, while the Rita and Ike storm deposits have low organic matter (<5%) and only contain 10-20% water (Yao, Liu, & Ryu, 2018).

X-ray fluorescence is a nondestructive analytical technique that can determine the elemental composition of materials. It is a well-established technique that allows sediment cores to be scanned at high precision (Oliva, Peros, & Viau, 2017). This technique has been used in numerous studies to directly identify tropical cyclone overwash sediments. However, the elemental signature of the overwash deposits varies across studies. Ramirez-Herrera et al (2012) used a multi-proxy approach on the coast of Mexico. There were two sand units within the clayey silt of the sediment core. Elements present in the sand units included silicon (Si), potassium (K), phosphorus (P), strontium (Sr), barium (Ba), zirconium (Zr) and calcium (Ca). An increase in Si and K within the sand units can be attributed to an increase in quartz and feldspar, which is found in more abundance in the sand unit then in the underlying clayey silt. This is consistent with the sand in a beach area sugesting the sand unit came from a beach environment. Increase in Sr, Ba, and Ca in the sand unit suggests a marine influence. Particularly, Sr and Ba usually appear in higher concentrations in seawater than freshwater, therefore, they can be used as signs of marine flooding (Ramirez-Herrera et.al, 2012). Woodruff (2009) focused on using strontium (Sr) as an indicator of storm deposits because during overwash events, it can be found in high concentrations within algal material, marine shells, and coral. Cl/Br ratio is also used to identify marine sediments (Liu et. al 2014, Yao et. al, 2019). Yao et. al (2019) claim that washover sediments can be identified by an increase in Cl/Br ratio. All the cores collected in their study did not have distinct sand layers due to a lack of overwash processes. However, marine flooding was still able to be identified using the increase in Cl/Br ratio.

1.4 Study Objectives

This research project focuses on using a multi-proxy approach, including recently developed XRF-based elemental analysis, to discriminate between overwash and non-hurricane marsh sediments (including fluvial flood deposits) within the bed of a coastal lake. The main objectives are to collect cores from an area of marsh in McFaddin National Wildlife Refuge (MNWR), which is known to contain overwash deposits from four recent hurricanes (Hodge and Williams, 2016); conduct multi-proxy analyses of the cores and use the findings to identify hurricane deposits in cores from the bed of Clam Lake, a large brackish lake which is also located on MNWR. These objectives will help answer the following research questions: First, what is the multi-proxy signature of hurricane overwash sediments in MNWR? Secondly, can the multi-proxy signature be used to identify hurricane deposits in the bed of Clam Lake? Thirdly, do all four hurricane layers have the same multi-proxy signature? This research fills a conceptual gap of knowledge because using XRF to identify hurricane sediments in a coastal lake bed is a novel untested application for this new analytical tool.

CHAPTER 2

STUDY AREA

2.1 Description of Study Area

McFaddin National Wildlife Refuge is located in the southeastern corner of Texas in Jefferson County. The refuge is about 20 km southwest of Sabine Past (Williams, 2010). It consists of 238 km2 of marshes and lakes (Williams & Liu, 2019). The marsh is generally classified as irregularly flooded estuarine intertidal emergent wetlands and ranges in elevation from 0 to 1 m above NAVD88 (Williams & Liu, 2019).

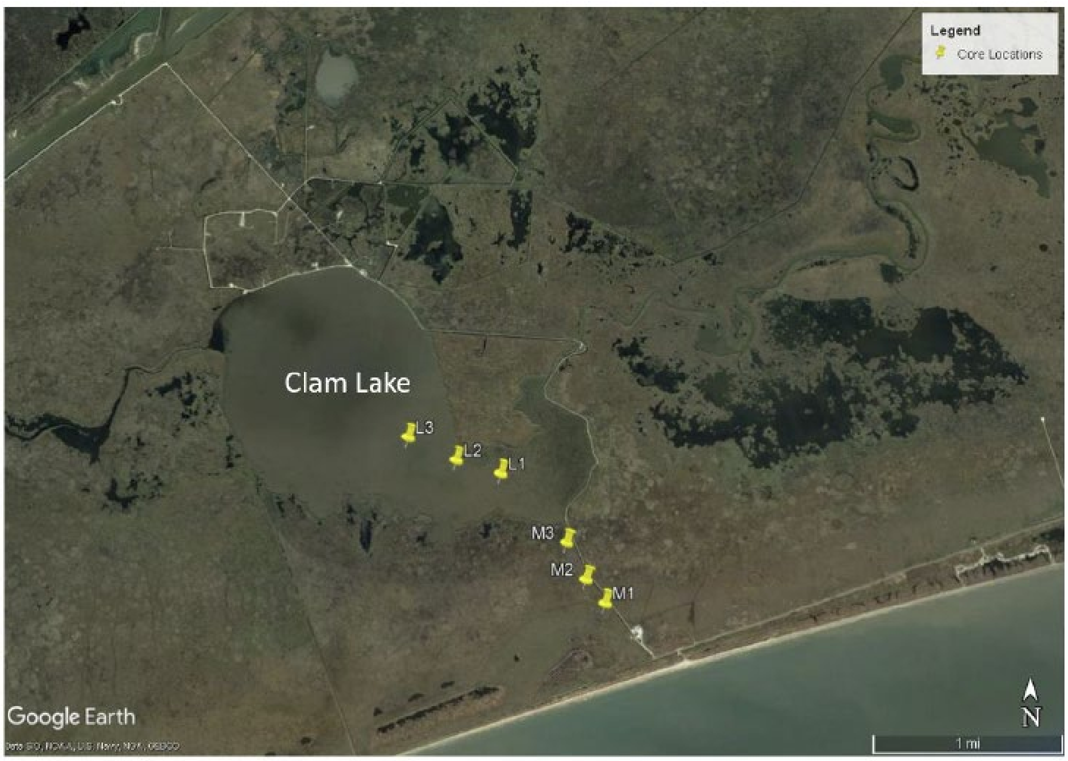


Figure 2.1: McFaddin National Wildlife Refuge. Locations of sediment cores are shown. L: lake cores; M: marsh cores.

The refuge has quite a few natural lakes;this study focuses on Clam Lake; the largest lake within the refuge approximately 1500m inland from the Gulf of Mexico (Williams, 2010). Because ditches connect the lake to the Gulf Intercoastal Waterway and Sabine Pass, the lake is classified as a tidally-influenced brackish lake (Williams, 2010).The lake is approximately at sea level making it the lowest elevation within the study area. The seaward edge of the refuge is bordered by Highway 87 and a wide sandy beach that is backed by low discontinuous foredunes (Hodge & Williams, 2016). The Gulf Intercoastal Waterway, a man-made canal, borders the northern edge of the refuge (Williams & Liu, 2019).

2.2 Previous Studies

This study builds upon three earlier studies at MNWR (Williams, 2010; Hodges and Williams, 2016; Williams and Liu, 2019). Williams (2010) documented the character of hurricane Ike's storm surge sedimentation on MNWR The study characterized Ike's storm surge sedimentation in terms of stratigraphy, foraminiferal content, and sediment texture. Sixteen weeks after Hurricane Ike made landfall, thirteen pits were excavated along a transect from the shore to inland. In addition, three cores were collected from Clam Lake. The Hurricane Ike washover deposit was thick, sandy and of low organic content near the shore and became thinner, less sandy and more organic farther inland. This is usual considering that storm surges and waves lose energy as they move inland. The cores collected from Clam Lake had no obvious sand layers and appeared as a grey sandy mud. Foraminifers are also indicators of intrusion of marine waters. Key foraminifers found in the marsh and lake by Williams (2010) consisted of *Ammonia sp., Buliminella sp., Elphidium sp., Haynesina sp.* and *Quinqueloculina sp.* which are all generally associated with bays and shallow offshore environments and were presumably transported inland by the storm surge. However, foraminifers were not found in lower parts of the lake sediment cores suggesting that foraminifera do not preserve well in the lake.

Hodge and Williams (2016) cored the same 13 pit locations used in Williams' (2010) study. After identifying Hurricane Ike's deposit in the cores, which was visibly identifiable in all of the cores, they used it as a modern analog to identify older hurricane layers. Four distinct sand beds were visible. Hurricane Ike's deposit was near the top of the core with another visible sand bed (Bed 2) only a short depth below. Near the bottom of the core, 2 thinner sand beds are visible (Bed 3 &4; Fig. 2.2).

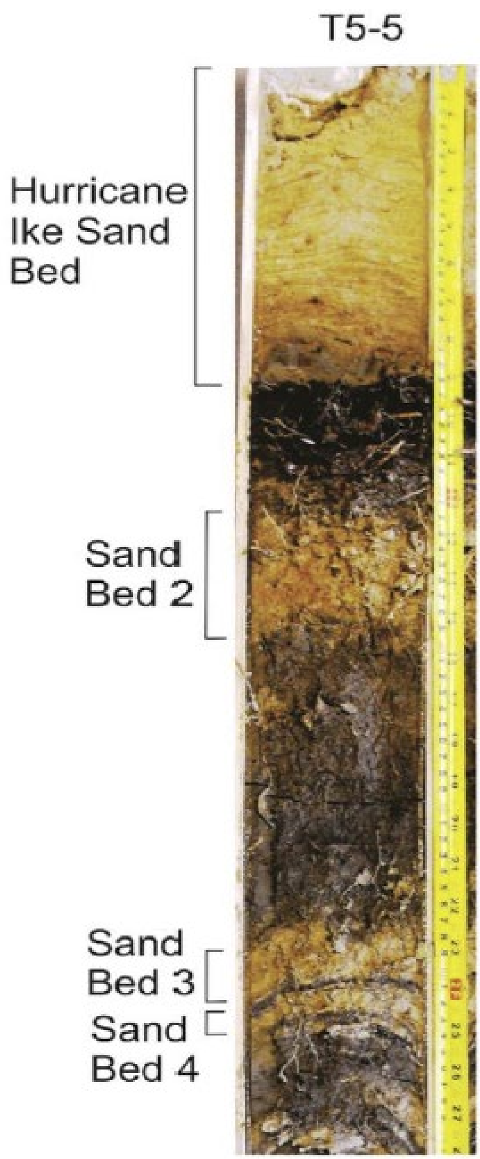


Figure 2.2: Core T5-5 displaying the Hurricane Ike sand bed and sand beds 2, 3, and 4. (Hodge and Williams, 2016).

Hodge and Williams (2016) found that 23 hurricanes made landfall within 300 km of the study site. Based on storm tide, wind speed and Cesium-137 dating, they concluded that it is likely that the four washover sand beds were deposited by Hurricanes Ike (2008), Rita (2005), Carla (1961), and Audrey (1957). The presence of these sand beds in the marsh south of Clam Lake suggests that the same washover deposits are likely present in the lake bed (Table 2.1).

Table 2.1: Hurricanes making landfall within a 300 km radius of the study site from 1950-2014. Ordered by storm tide height (Hodge and Williams, 2016)..

Year	Name	Category at landfall	Landfall proximity to study area (km) (East or West)	Conditions in vicinity of study area[1]	
				Storm tide[2] (m) (location)	Maximum sustained winds (kts) (location)
2008	Ike	2	75 (W)	4.31 (SP)[a]	65 (SP)[a]
2005	Rita	3	33 (E)	2.81 (PA)[b]	61 (PA)[b]
1957	Audrey	4	35 (E)	2.79 (SP)[c]	74 (SP)[d]
1961	Carla	4	290 (W)	2.25 (SP)[e]	76 (G)[f]
1986	Bonnie	1	26 (W)	1.64 (SP)[g]	54 (PA)[h]
2002	Lili	1	173 (E)	1.64 (BAP)[i]	27 (BAP)[i]
1983	Alicia	3	117 (W)	1.59 (HI)[j]	35 (PA)[k]
2007	Humberto	1	35 (W)	1.47 (TPNWR)[l]	52 (MNWR)[l]
1971	Edith	2	123 (E)	1.21 (SP)[m]	30 (SP)[m]
1989	Chantal	1	36 (W)	1.19 (SRSP)[n]	47 (HI)[n]
1963	Cindy	1	37 (W)	1.15 (SP)[o]	36 (PA)[o]
2003	Claudette	1	272 (W)	1.01 (RP)[p]	45 (SRSP)[p]
2008	Gustav	2	322 (E)	0.85 (SP)[q]	32 (SP)[q]
1964	Hilda	2	240 (E)	0.78 (SP)[r]	30 (SP)[r]
1989	Jerry	1	102 (W)	0.69 (SP)[s]	41 (GWSO)[s]
1959	Debra	1	115 (W)	0.48 (HI)[t]	39 (HI)[t]
1992	Andrew	3	262 (E)	0.39 (SP)[u]	22 (PA)[u]
1985	Juan	1	245 (E)	1.1[3] (SP)[v]	27 (PA)[v]
1985	Danny	1	130 (E)	0.9[3] (SP)[v]	19 (PA)[v]
2012	Isaac	1	330 (E)	N/A	30 (SP)[w]
1974	Carmen	3	275 (E)	N/A	N/A
1965	Betsy	3	330 (E)	N/A	N/A
1977	Babe	1	267 (E)	N/A	N/A

Location key: SP: Sabine Pass, G: Galveston, PA: Port Arthur, BAP: Beaumont Air Port, HI: High Island, TPNWR: Texas Point National Wildlife Refuge, MNWR: McFaddin National Wildlife Refuge, SRSP: Sea Rim State Park, RP: Rollover Pass.
N/A: significant hurricane-related conditions not recorded in vicinity of study area.
Wind and tide data sources: [a]Berg, 2009; [b]Knabb et al., 2006; [c]Moore, 1957; [d]Landreneau and Shamburger, 2009; [e]Ho and Miller, 1982; [f]U.S. Weather Bureau, 1961; [g]National Weather Service, 2016; [h]Lawrence, 1987; [i]Lawrence, 2002; [j]Case and Gerrish, 1983; [k]National Hurricane Center, 1983; [l]Blake, 2007; [m]Simpson and Hope, 1971; [n]Case and Mayfield, 1990; [o]U.S. Weather Bureau, 1963; [p]Beven, 2003; [q]Beven and Kimberlain, 2014; [r]Dunn et al., 1964; [s]Case and Mayfield, 1990; [t]U.S. Weather Bureau, 1959; [u]Rappaport, 1993; [v]Case, 1985; [w]Berg, 2013.
[1] Tide and wind record locations were selected for close proximity to MNWR study area.
[2] Storm tide is normal tide plus storm surge (NAVD88).
[3] Height above normal tide.

Findings by Williams and Liu (2019) suggest that flood sediment carried into marshes by terrestrial flood waters may also be present in the bed of Clam Lake. Hurricane Harvey flood deposits were found to be widespread on MNWR. Figure 2.3 shows rapid response imagery acquired a few days after the passage of Hurricane Harvey; plumes of suspended sediments in terrestrial flood waters are shown flowing into McFaddin National Wildlife Refuge and Clam Lake.

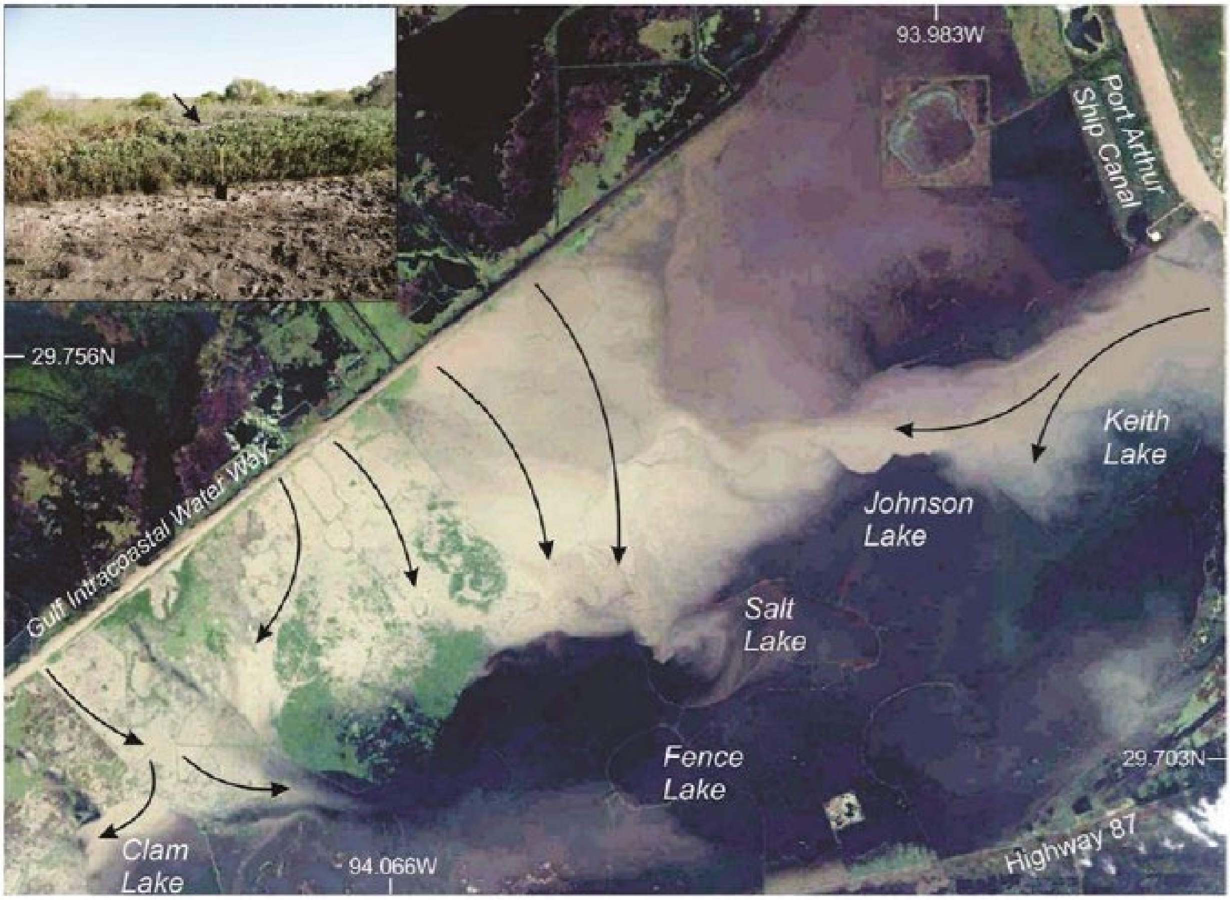


Figure 2.3: Plumes of suspended sediment being carried by flood waters into marshes on MNWR. Clam Lake is at the bottom left. (Williams and Liu 2019).

CHAPTER 3

METHODS

3.1 Field Work

Sediment cores were obtained February 29 and March 1 2020. On February 29 a GPS was used to guide a flat bottom aluminum boat to three locations within Clam Lake for coring. A 10ft aluminum tube was manually pushed into the lake bed (Fig. 3.1). The lake bed sediments were fairly soft, allowing the tubes to easily be pushed in. The tubes were fitted with a core-retaining device at the end so when the cores were pulled up, they would not slip out. The cores were about 1-1.5 m in length. Excess tube was sawed off with a hand saw. Duct tape was then used at both ends of the tube to secure the core.

Figure 3.1: Pushing an aluminum core tube into the lake bed.

Three cores were also collected from the marsh south of Clam Lake. Cores were located along the same transect used by Hodge and Williams (2016), where four hurricane overwash deposits had been identified in the subsurface. A GPS was used to guide an ATV to the sample locations. The marsh sediment was harder than the lake bed sediment, so a sledge hammer was used to drive the tube into the ground. A hand-operated jack was then used to pull the tubes out of the marsh. The excess tube was sawed off and the tubes were sealed with duct tape at both ends (Figure 3.2). Compaction, caused by hammering, was accounted for in each marsh core. All cores collected were labeled with either an L# or M# referring to lake or marsh.

Figure 3.2: (a) Sawing off excess core tube in the marsh to the south of Clam Lake. (b) Placing a vacuum seal into a core tube prior to retrieval.

3.2 Lab Analyses

The cores were transported back to the geomorphology lab at UNT where they were analyzed. Core sediments were examined using LOI (Loss-on-ignition) and XRF (X-ray fluorescence). The cores were cut in half lengthwise and one half of the core was sampled at 1-cm intervals for moisture, organic, sand, and carbonate content, using Loss-On-Ignition Analysis. The other half of the core was taken to the LSU paleoecology lab where it was analyzed at 1-cm intervals using X-ray fluorescence (XRF) analysis.

3.3 Loss-On-Ignition

For consistency, the LOI procedures used in this project follow Heiri et al (2001). The cores were sampled at 1-cm intervals, half of the sample was placed in a crucible while the other half (subsample) in a bottle. The sample in the crucible was weighed and placed inside the furnace at 105 degrees Celsius for 24 hours then re weighed to estimate moisture content of the sample. The sample was then put back in the furnace at 550 degrees Celsius for 4 hours, then reweighed to determine the organic matter content. Lastly, the sample was placed back in the furnace at 950 degrees Celsius for 2 hours to determine the carbonate mineral content. The subsample that was placed in the bottle was weighed and wet sieved using a 63 um sieve, air dried, and weighed again to calculate the sand fraction.

3.4 X-Ray Fluorescence

XRF is an analytical technique that is used to determine the elemental composition of materials (Yao et. al, 2019). Elements present in a sample will produce a fluorescent X-ray when a solid or liquid is excited by a primary X-ray source. The XRF measures this energy and determines the elements relative concentration in ppm. Yao et al (2019) found 9 common elements in their study, including the Cl/Br ratio which has successfully been used to identify marine sediment in coastal environments. Fe (Iron) and Ti (Titanium) are examples of elements that previous studies have successfully used as terrestrial runoff indicators (Yao et. al, 2019) while Sr and Ca are typically abundant in saltwater and are used as indicators of marine intrusion (McCloskey et al. 2018).

A handheld Olympus Innov-XDelta premium XRF analyzer was used to scan the cores. The cores were analyzed at 1cm intervals and scanned for 90 seconds each to identify the elements. This method has the potential for human error. Inconsistency occurs while identifying the starting point (0 cm) of the core, as well as, trying to align the handheld scanner with each cm of core. For example, Figure 3.4 demonstrates that the top of cores may not be level and has loose material. Determining the first cm of each core can vary, resulting in some variation between the XRF graphs, LOI graphs, and photographs. Sampling at 1cm intervals also is not without the potential for error. Holding the handheld scanner exactly at every cm interval is challenging and not always precise. Additionally, using a 1cm interval does not account for any differences in smaller intervals, for example a ½ cm thick sand layer. These potential errors probably introduce some uncertainty into the XRF findings but are unlikely to obscure the overall results.

A total of 16 elements were detected across all 6 cores (S, Cl, Ca, Sr, Zr, Br, K, Ti, Fe, V, Mn, Cr, Zn, Rb, Ba, Pb). A combination of LOI results (Fig. 3.3) and photographs (Fig. 3.4) were used to identify the depths of the hurricane sand layers in the marsh cores. Once determined, the intervals were highlighted on the XRF graphs to identify any contrast in elemental concentration between overwash and marsh sediments.

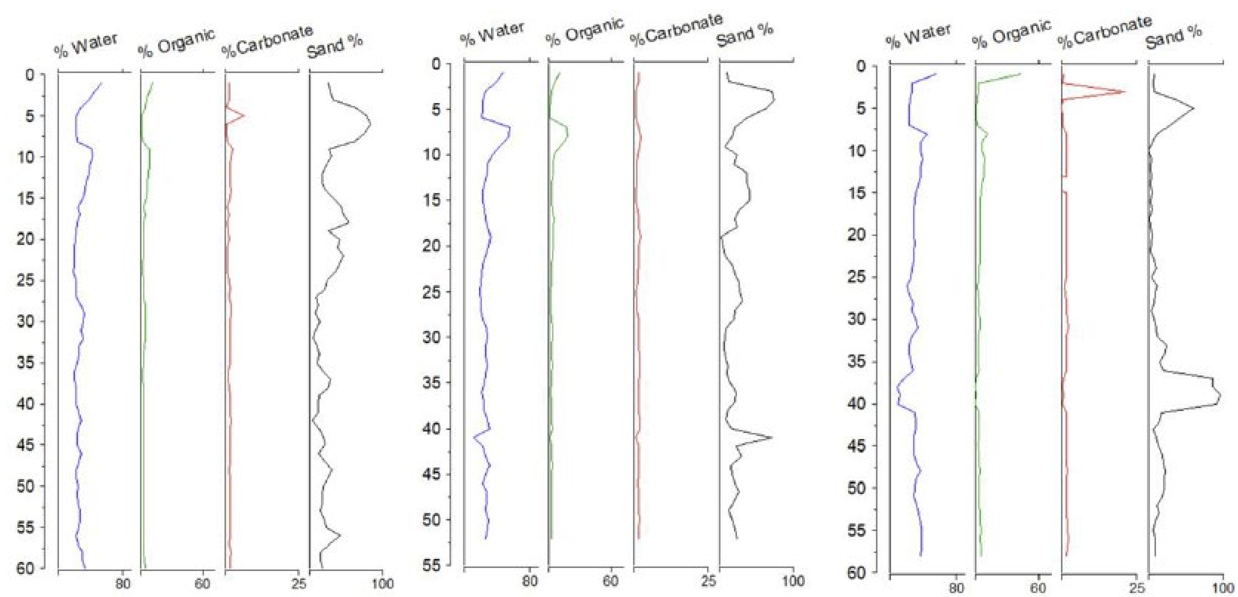


Figure 3.3: LOI graphs displayed left from right: M1, M2, and M3.

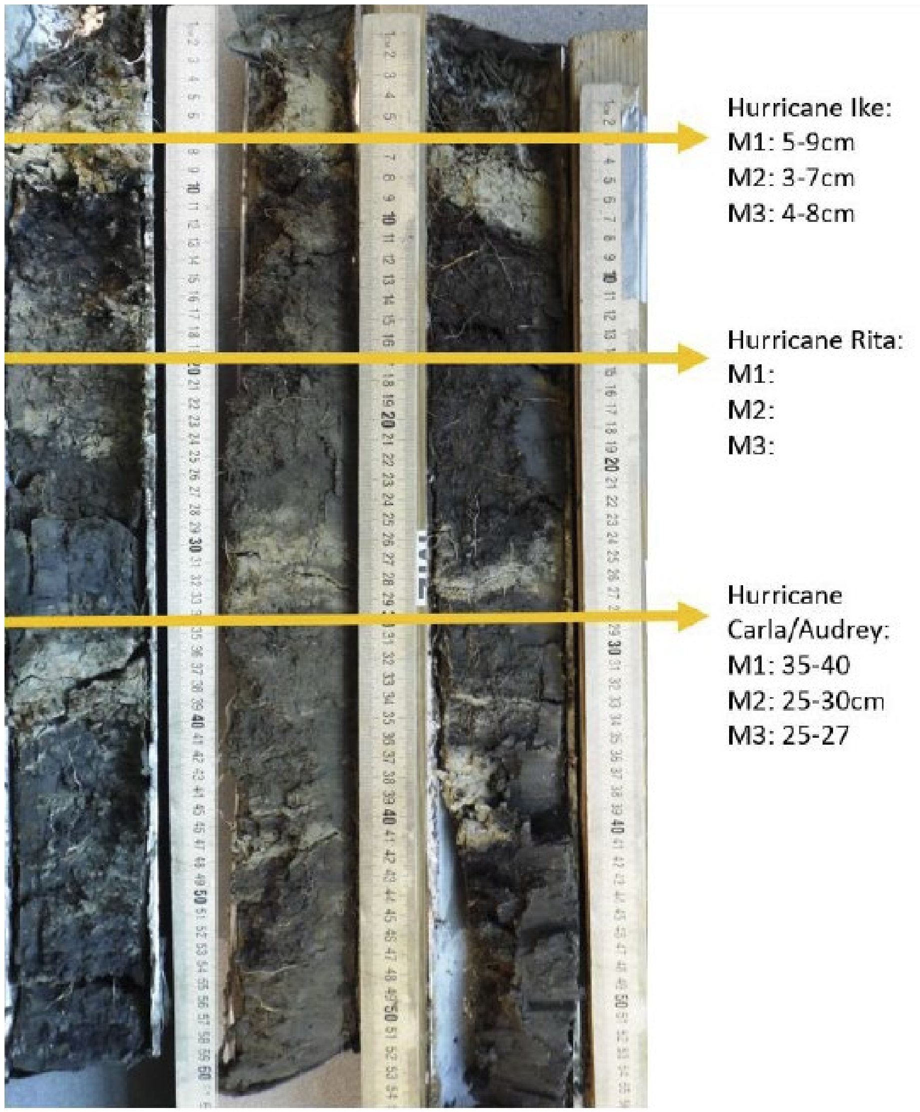


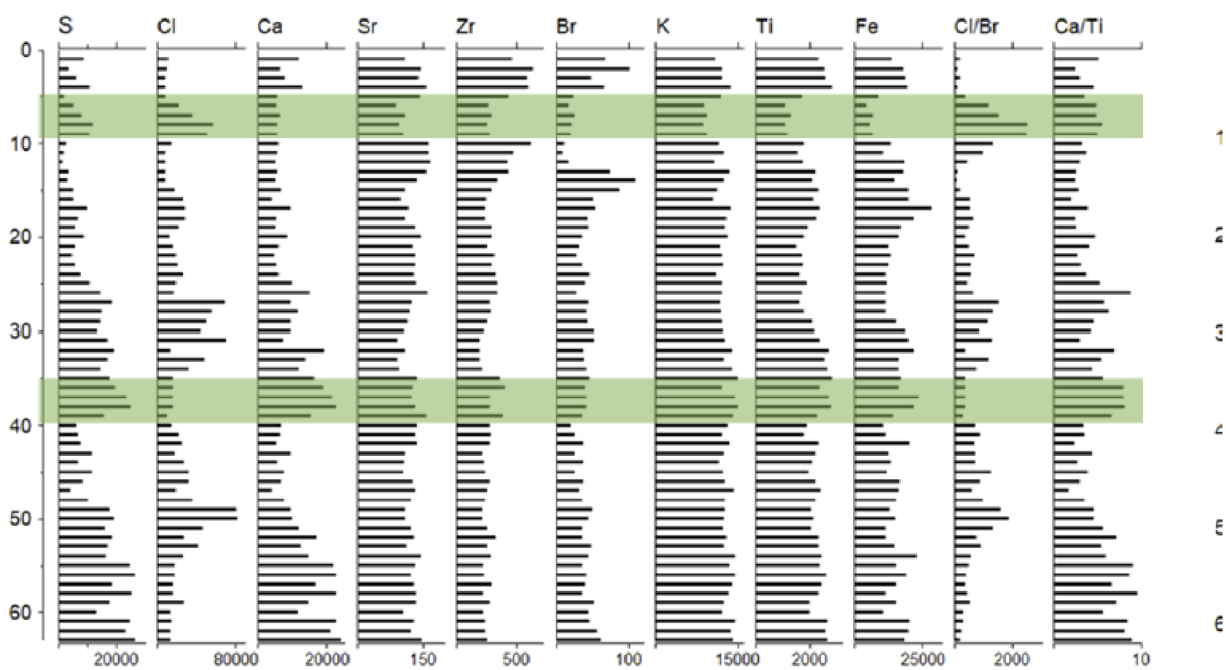
Figure 3.4: Marsh core photos from left to right M1, M2, and M3.

Yellow arrows line up the hurricane overwash layers from Hurricane Ike, Rita, and Carla/Audrey. Hurricanes Carla and Audrey are referred to as one overwash layer because they are mixed. Hurricane Rita was removed at this time from the analysis because it did not display a visible sand layer or clear LOI results across all 3 marsh cores, therefore, the depth could not be determined.

3.5 Cluster Analysis

Hierarchal cluster analysis (HCA) was used to determine the effectiveness of XRF in distinguishing between washover and terrestrial sediments. HCA is able to group together samples based on similarities in their elemental compositions.. The data was normalized at a range of 0-1 before being analyzed to stop elements with large values from being given more contribution then ones with smaller values. The approach used was to identify elements that showed a contrast in elemental composition between washover and marsh samples. Contrasting elements were selected from each marsh core. The best combination of contrasting elements was chosen through trial and error with the HCA. Clusters ranging from 2-5 were selected to categorize the elements in each core.

Elements that contrasted between the known washover deposits and enclosing marsh sediments for core M1 were sulpher (S), chlorine (Cl), zinc (Zn), iron (Fe), titanium (Ti), strontium (Sr), zirconium (Zr), and calcium (Ca) (Fig. 3.5). M2 had 7 contrasting elements including Zr, Cr (chromium), Zn, Rb (rubdium), Br (bromine), Ti, and Fe (Fig. 3.6). The selected elements for M3 were S, Cl, Ca, Sr, Zr, Rb, and Zn (Fig. 3.7). Because the elements selected varied between each core, the most common elements between all 3 cores was chosen (S, Cl, Ca, Sr, Zr, Zn, Ti, Fe, Rb) and used as the best set of elements to run HCA on the lake cores.



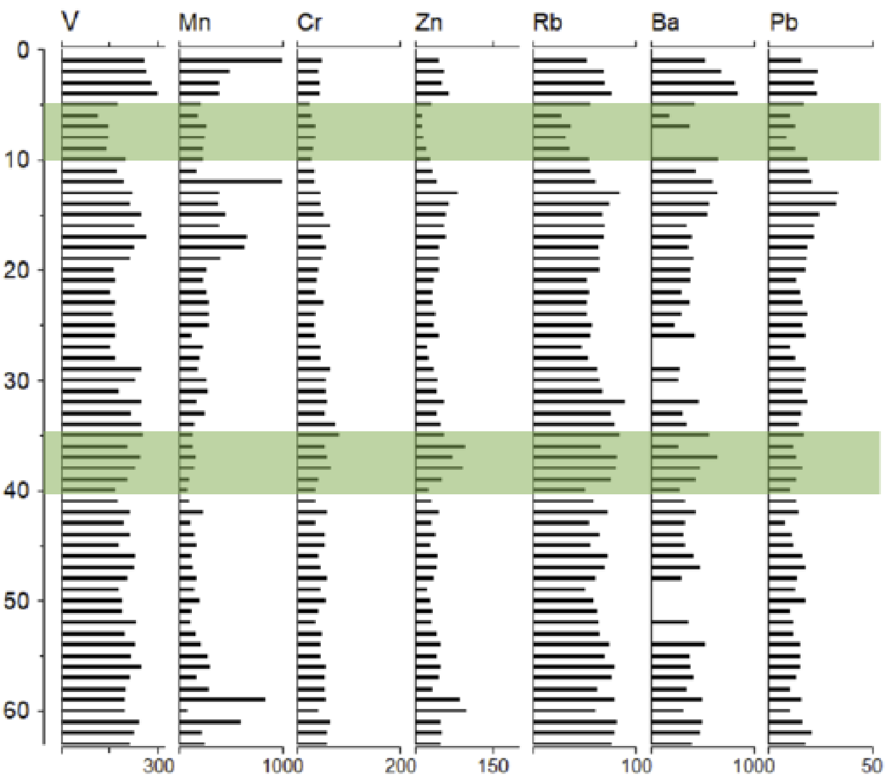
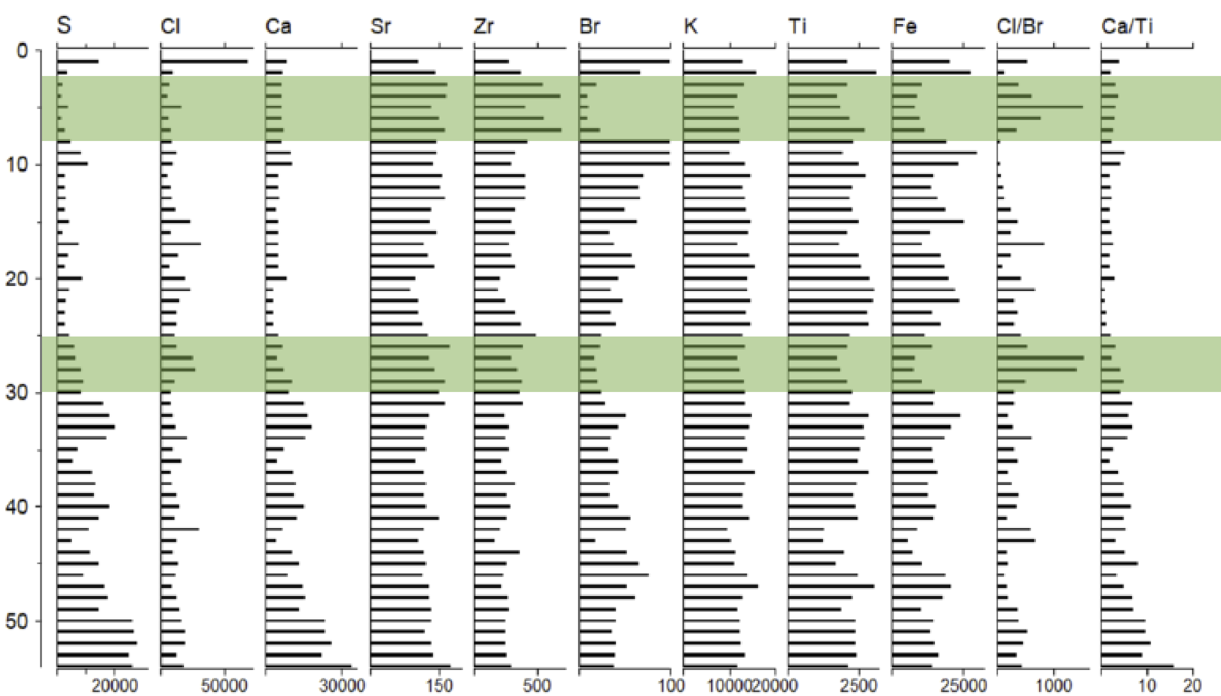


Figure 3.5: Elemental compositions of samples in core M1. Green bars represent overwash layers of Hurricane Ike (upper bar) and Hurricanes Carla/Audrey (lower bar).



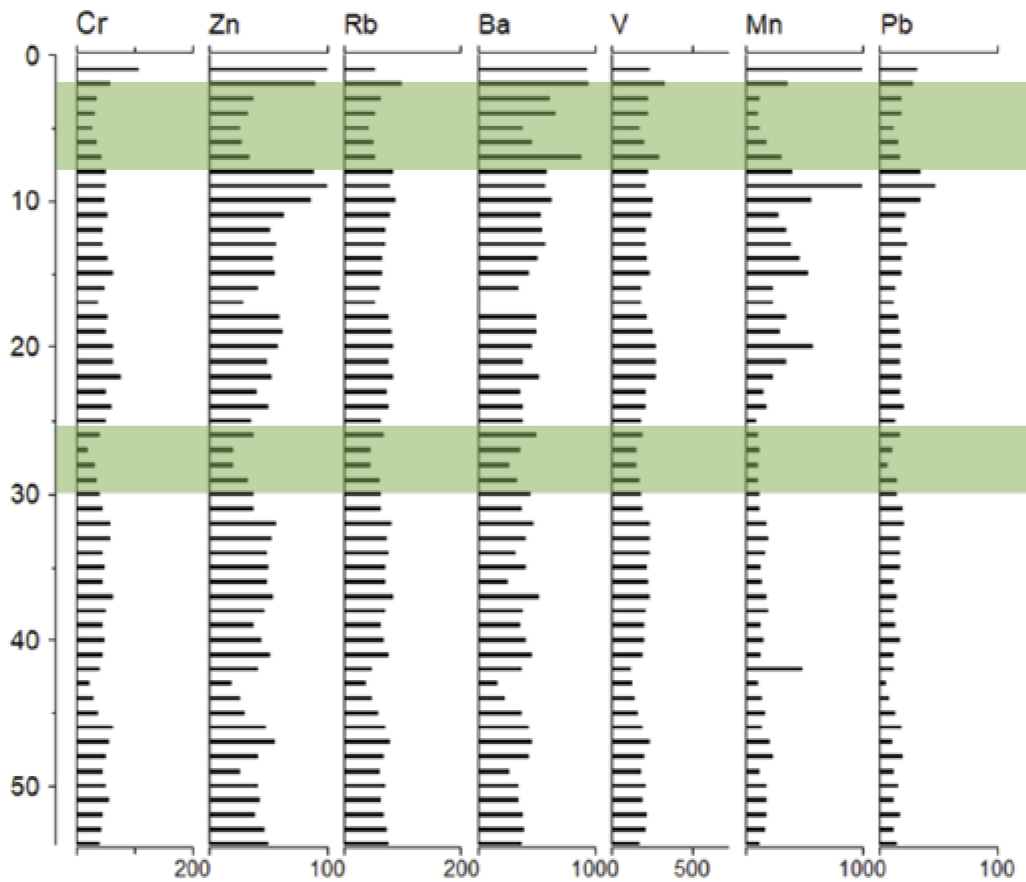
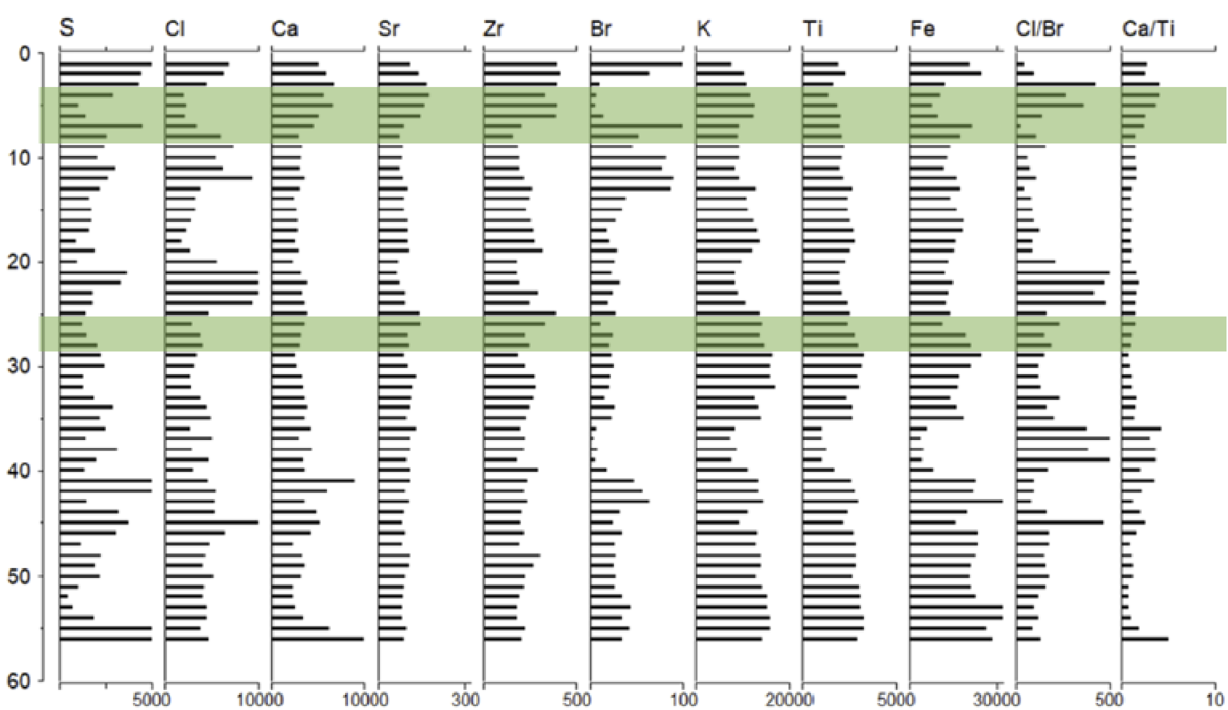


Figure 3.6: Elemental composition of samples in core M2.



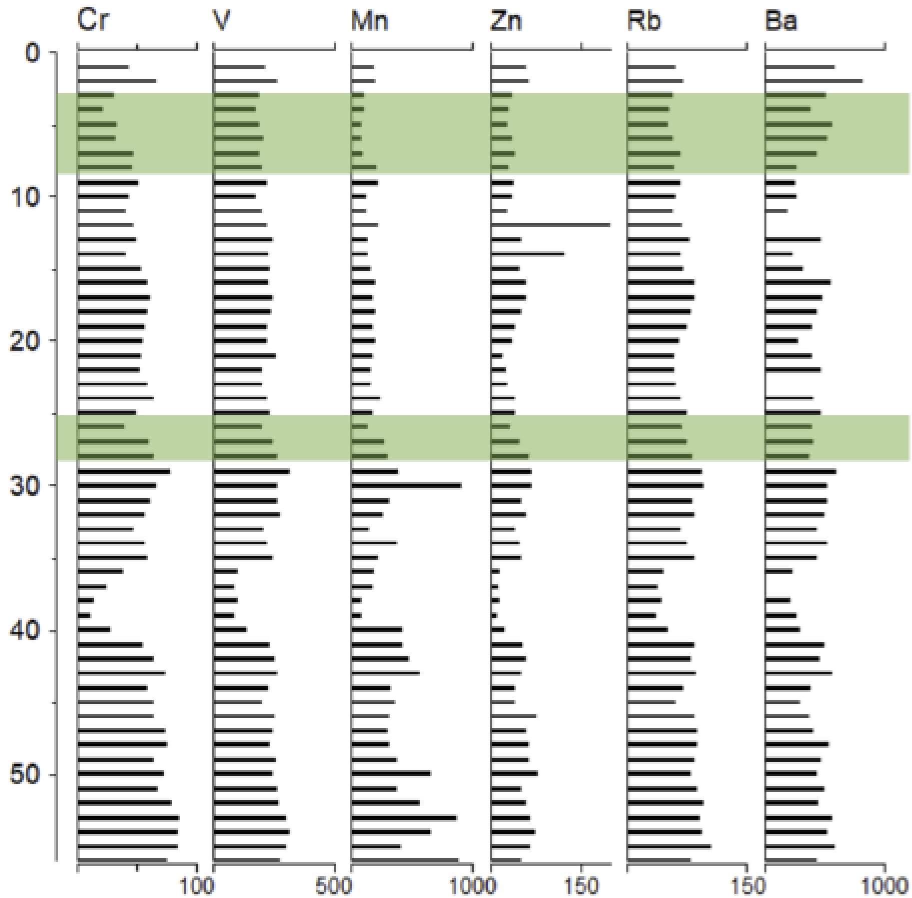


Figure 3.7: Elemental composition of samples in core M3.

CHAPTER 4

RESULTS

4.1 Marsh Cores Cluster Analysis Results

For the marsh cores, 4 clusters divided the cores into groups that correlate with known overwash layers and marsh. For core M1 (Fig. 4.1), cluster 3 correlates with Hurricane Ike overwash. Clusters 1 and 2 represent marsh. Cluster 2 is found at the top of the core before Hurricane Ike and after, presumably before, Hurricane Rita. Cluster 1 seems to be marsh since it is found surrounded by marsh sediments. Cluster 4 correlates with Hurricanes Carla/Audrey and is classified as overwash. It is noticeable on the XRF graphs (Fig. 3.5) that Hurricane Ike's and Hurricanes Carla's/Audrey's elemental signature contradict one another. For example, Hurricane Ike can be characterized with sharp increase in Cl, and a sharp decrease in Sr and Zr compared to the surrounding marsh sediments and no noticeable contrast in Ca; whereas Hurricanes Carla/Audrey have a significant increase in Ca, Sr, Zr, and decrease in Cl with little contrast in the other selected elements. This could have affected the clustering and explain why Hurricanes Carla/Audrey are grouped differently than Hurricane Ike. At 54-60 cm, cluster 4 looks to be surrounded by marsh sediments, though, LOI results show an increase in sand percentage at this depth. This further supports the idea that cluster 4 overwash.

Core M2 presented “cleaner” cluster results than M1 (Fig. 4.2). Cluster 3 correlates with both Hurricane Ike and Hurricanes Carla/Audrey overwash layers. It is also seen further down the core at 41-46cm and 49-50cm which is associated with higher sand percentages (Fig. 3.3) and visible sand in the core. Cluster 1 and 2 correlate with marsh sediments. Cluster 2 is even found at 26-27cm, in the middle of Hurricanes Carla and Audrey.

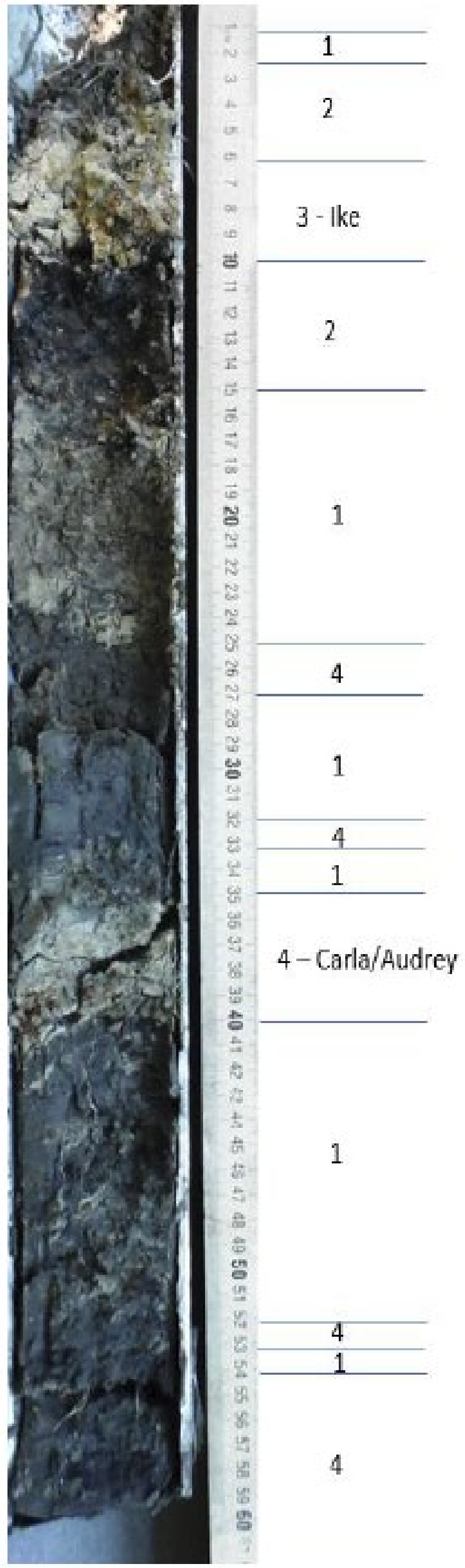


Figure 4.1: Core M1 cluster results. Cluster 3 correlates with Hurricane Ike. Cluster 1 and 2 correlate with marsh. Cluster 4 correlates with Hurricanes Carla and Audrey (C/A).

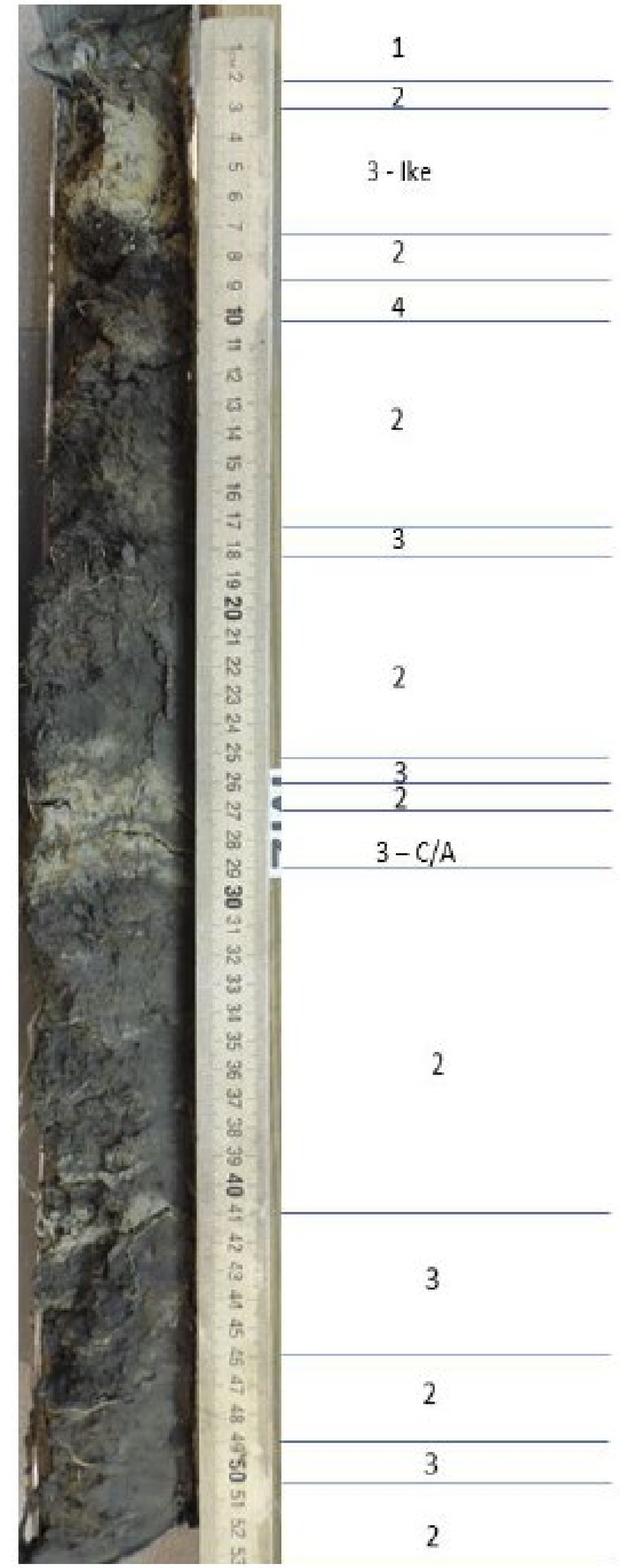


Figure 4.2: Core M2 cluster results. Cluster 3 correlates with Hurricane Ike and Hurricanes Carla and Audrey(C/A). 2 correlates with marsh.

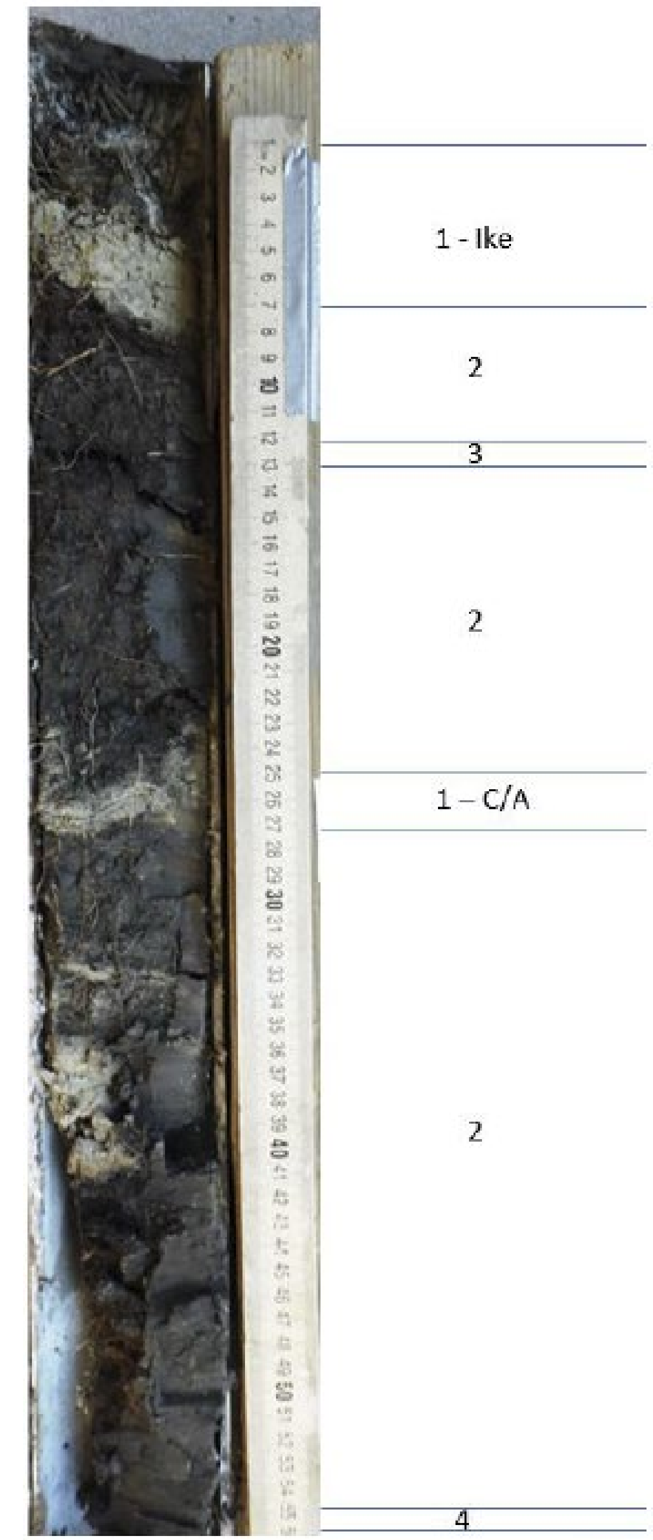


Figure 4.3: Core M3 cluster results. Cluster 1 correlates with Hurricane Ike and Hurricanes Carla and Audrey. 2 correlates with marsh.

This demonstrates that there are marsh sediments encompassed between Carla and Audrey's' overwash layers. Cluster 4 can be designated as marsh because there is no visible sand and is surrounded by marsh sediments at this depth. A probable reason for it to be clustered different is because it contains the highest concentrations of Zn and Br.

Core M3 has the least amount of variance between the clustering (Fig. 4.3). Cluster 2, designated as marsh, equals roughly 80% of the core. Cluster 1 correlates with Hurricane Ike and Hurricanes Carla/Audrey. Clusters 3 and 4 are only sampled at 1 cm, 12-13cm and 55-56cm respectively and are designated as marsh. They are clustered separately because 12-13cm has unusually high concentrations of Cl, Zn, and S while 55-56cm has high concentrations of S and Ca.

4.2 Clam Lake Bed Cores Cluster Analysis Results

The best set of elements selected from the marsh cores (S, Cl, Ca, Sr, Zr, Zn, Fe, Ti, Rb) were used to run the HCA on the lake cores. While these cores are over 100cm in length, the first 60cm are pictured for figures to align with the marsh cores. There are no visible sand layers in the lake cores and overwash layers cannot be concretely distinguished, however, the cluster analysis did pick up variations and assumptions can be made. XRF analysis of core L1 produced 4 clusters (Fig. 4.4). Cluster 2 makes up most of the core and is assumed to be "marsh" (non-hurricane sedimentation). Cluster 3 and 1 could be hurricane overwash sediments since 3 is at the depth of the Hurricane Ike layers identified in the marsh cores.

Core L2 correlates well with core M1 (Fig. 4.5). Both are grouped mainly as cluster 1 and 4. The LOI results show that L2 has almost 50% sand between 5-10cm which correlates with cluster 1. Cluster 1 is also around the same depth as the Hurricane Ike layers in the marsh cores.

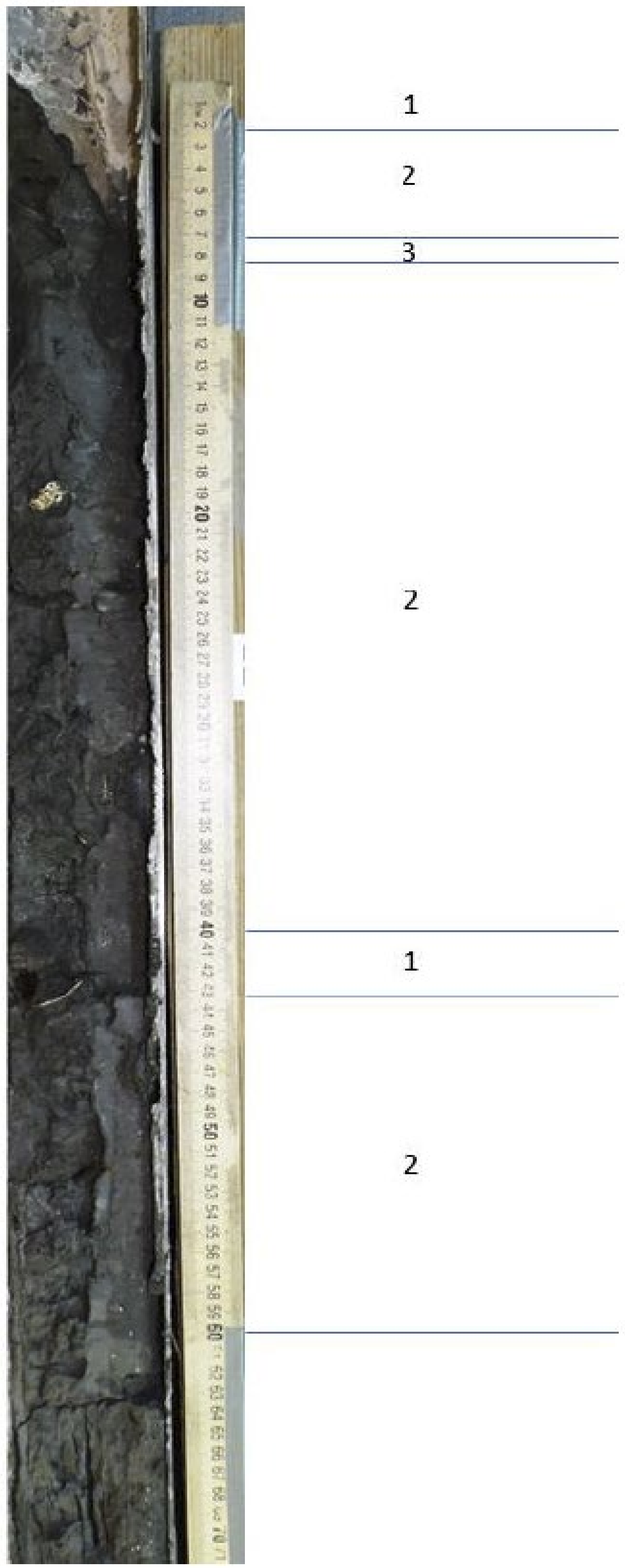


Figure 4.4: Core L1 cluster results.

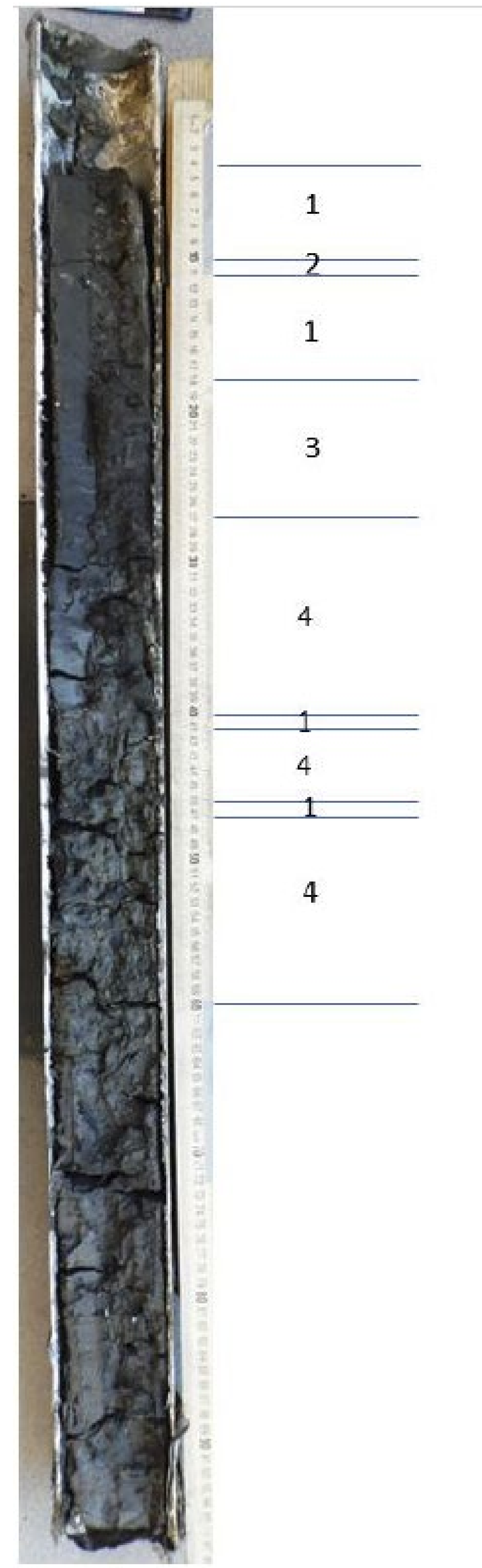


Figure 4.5: Core L2 cluster results.

Figure 4.6: Core L3 cluster results.

Core L3 (Fig. 4.6) is almost completely classified as cluster 2, which can be assumed to be “marsh,” while cluster 1 and 3 are aligned with the depths of the Hurricane Ike layers and also have a high sand percentage around 2-7cm depth (Fig. 4.7).

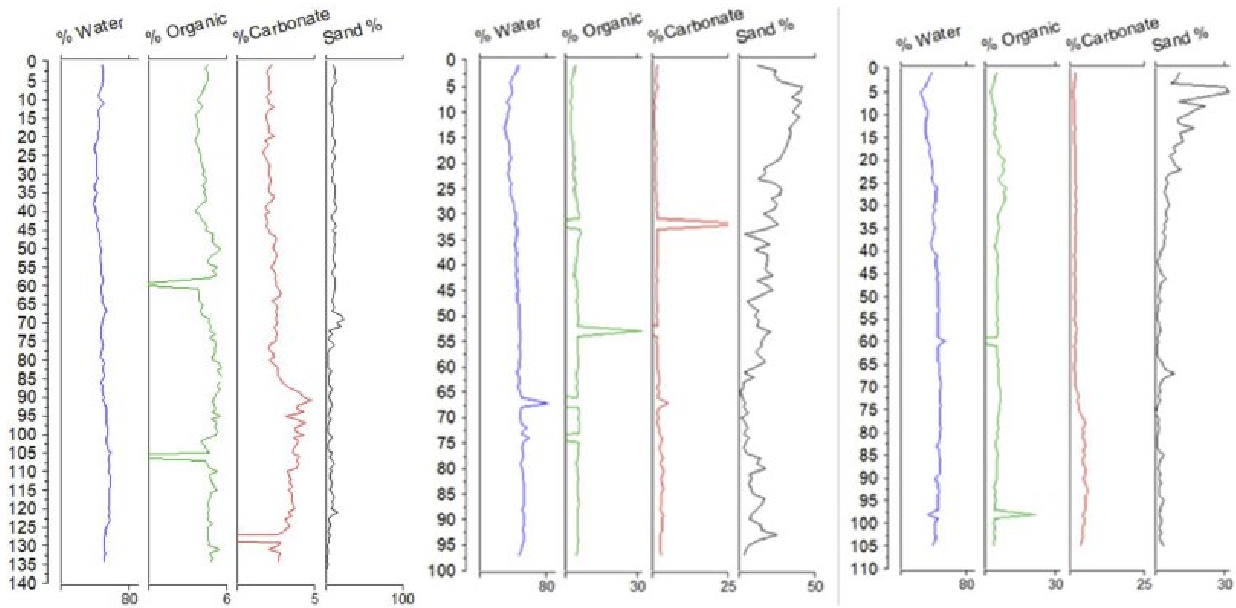


Figure 4.7: LOI results for Clam lakebed cores. From right to left, L1, L2, and L3.

CHAPTER 5

DISCUSSION

Overall, the application of a multiproxy signature of known washover layers to the identification of washover sediments in Clam Lake, produced some promising results. This technique was more successful in distinguishing between known overwash deposits and marsh sediments in the marsh cores, where the washover layers are more prominent and, mostly, visibly recognizable. The process of selecting the best set of elements used in clustering for each core was problematic, in that trial and error had to be used to find the elemental combination that gave the best cluster results. In addition, in core M1 there were contradicting contrasts in element concentrations between the Hurricane Ike and the Hurricane Carla/Audrey washover deposits. For example, Hurricane Ike overwash increases significantly in Cl, and decreases in Sr, and Zr while Hurricanes Carla/Audrey's overwash increases in Ca, Sr, Zr and decreases in Cl.

Core M2 has the most distinguishable differences between overwash and marsh. The cluster analysis identified both known overwash layers within the same cluster and identified the thin layer of marsh between Carla and Audrey and a sand layer of unknown origin at 40-45cm depth. In core M3 the deposits of Hurricane Ike and Hurricane Carla/Audrey were correctly placed in the same cluster and could be distinguished from the marsh.

Identifying washover layers in the lake bed sediments was more difficult because sand layers are not visible and sand contents are lower than in the marsh cores. Nevertheless, cluster analysis of the lake bed cores combined with LOI analysis does appear to offer the means of at least preliminary interpretation of washover and marsh deposits within the cores. Core L1 does not have very high sand percentages throughout the core, so cluster 2, the largest cluster, is assumed to represent marsh. Cluster 1 is found at the top of the core and at a depth of 40-45 cm. These depths approximately correspond to Hurricane Ike overwash in all three marsh cores and the unknown overwash layer at 40-45cm in core M2. The XRF analysis (Fig. 5.1) shows significant increases of Ca, Cl, and Sr at the depths of 40-45cm which correlates to cluster 1. The increase in those elements is also consistent with hurricane overwash deposits, making it likely that cluster 1 is washover.

Core L2 has significant changes in sand percentage throughout the core which could contribute to the disparity of clusters (Fig. 5.2). The largest sand content is near the top of the core, where a deposit of the recent Hurricane Ike could be expected. Cluster 2 is unique at a depth of about 10 cm and may represent this washover deposit. If this is the case, the cluster results do not indicate any other washover deposits within the core. Clusters 1, 3 and 4 are presumably marsh or mixtures of marsh and sediment from smaller-scale washover events, including Hurricanes Carla and Audrey.

Core L3 also has a prominent sand peak near the top of the core, again suggesting the presence of a washover deposit from Hurricane Ike (Fig. 5.3). Cluster 3 may represent Hurricane Ike because it is a single unique layer. Clusters 1 and 2 are presumed to be marsh or mixtures of marsh and sediment from smaller-scale washover events.

An advantage of the XRF technique is that it places every cm of a core into a cluster. This means that interpretation of a core provides a precise breakdown of overwash and non-overwash sediment. For example, in core M3, 8 cm, or 14% of the core, is interpreted as marine overwash deposits and the other 86% of the core is presumably marsh or marsh/overwash mixtures. All three lake cores show that apparently little overwash sediment is entering the lake, varying from 1% in core L2 to 10% in core L1.

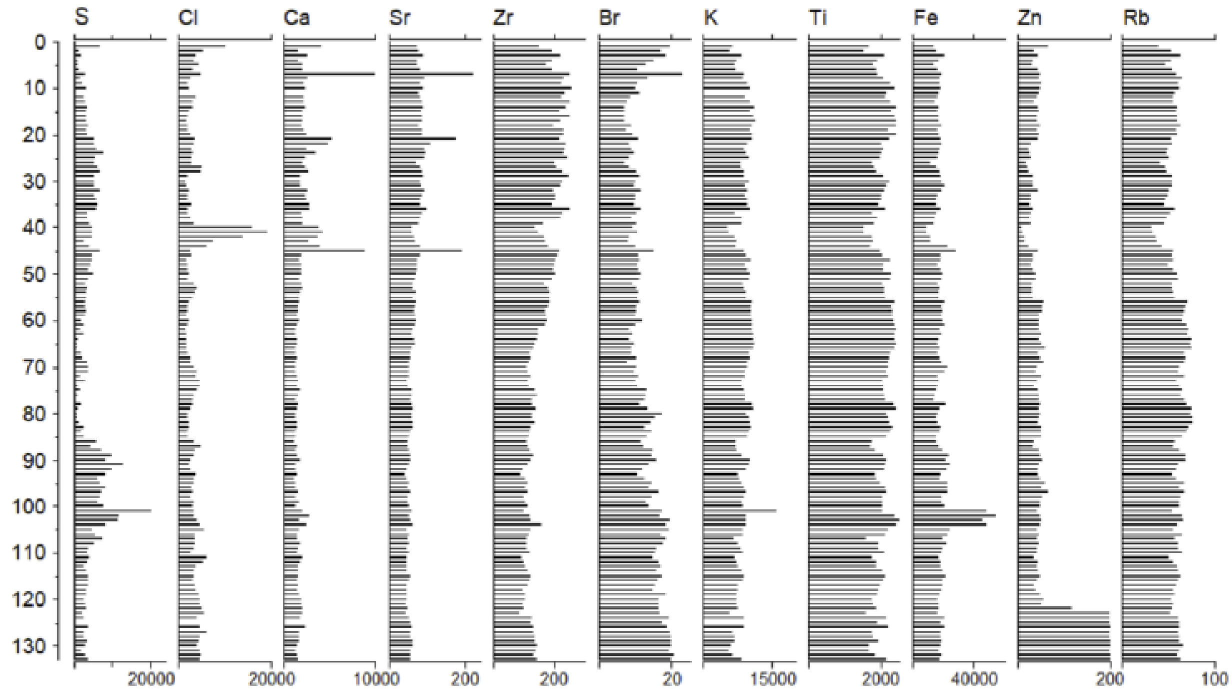


Figure 5.1: Elemental composition of samples in core L1.

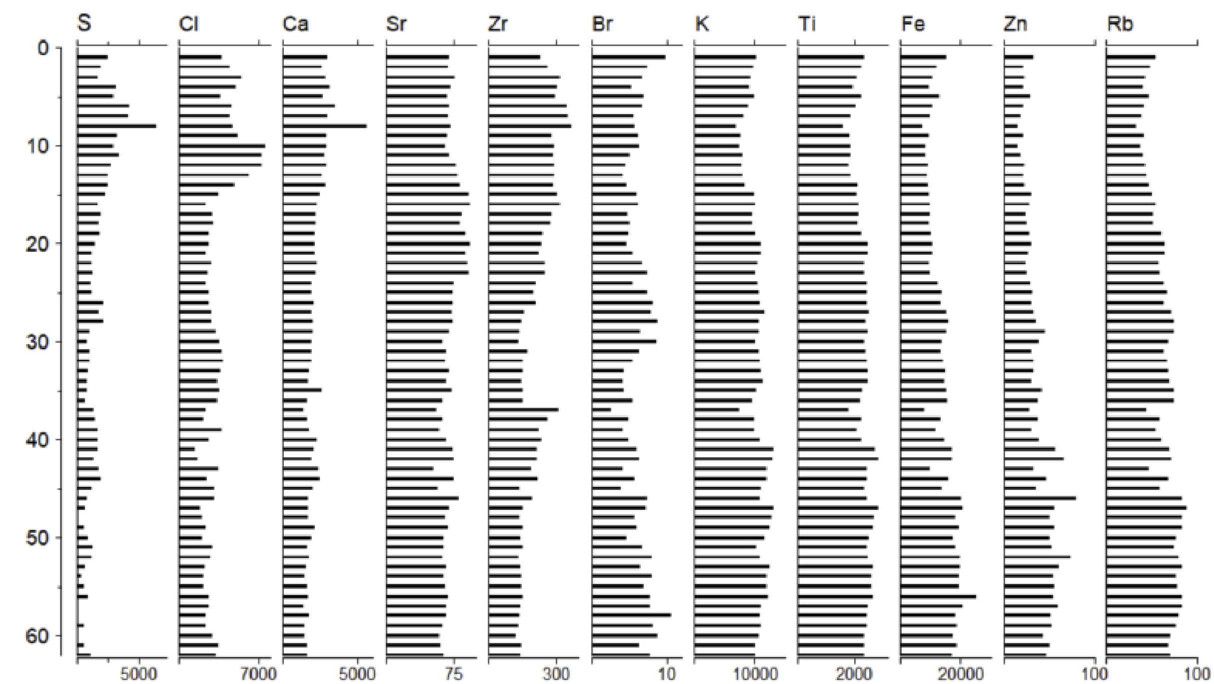


Figure 5.2: Elemental composition of samples in core L2.

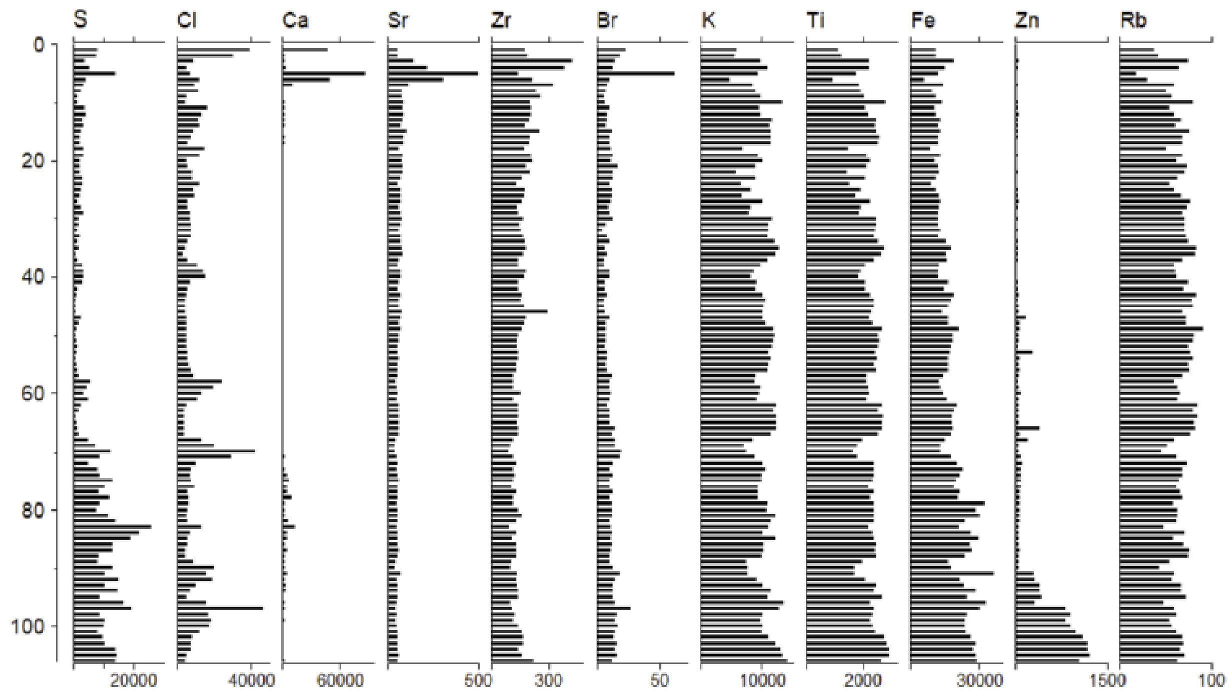


Figure 5.3: Elemental compositions of samples in core L3.

CHAPTER 6

CONCLUSION

This study demonstrates that cluster analysis combined with LOI and XRF can tentatively identify hurricane overwash deposits in the bed of Clam Lake. Results are somewhat inconsistent and uncertain, possibly because there was not a substantial amount of overwash deposits to identify or that the XRF analysis needs more distinct sandier layers to distinguish overwash from marsh. The study does add support to XRF's ability to distinguish overwash from marsh sediments. The ability to place every cm of a core into a cluster has the promise to enable more precise evaluation of the contributions of marine overwash and non-overwash sediments to marsh growth, which is key to understanding sediment sources and pathways. Further studies in other coastal marshes in a variety of settings, are needed to farther develop the XRF technique.

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