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Geomorphological responses of Biloxi Marsh platform due to variation in the volume and distribution of marsh-edge shell ridges during cold fronts and tropical storms

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Abstract

Wetlands in coastal Louisiana account for 37% of total wetlands in the United States, yet account for 90% of the total wetland loss. Recent research shows the percent of Louisiana's coastal wetland loss is decreasing, likely due to the lack of major hurricanes since 2008. The study area, Biloxi marsh, is located south of Lake Borgne and was formed by progradation of the St. Bernard delta complex. One unique geomorphologic feature of Biloxi marsh is the presence of oyster and clam shells, which wash onto the marsh platform and create shell ridges. *Crassostrea virginica* is the most common shell found in the area. Shell ridges can act as a buffer against erosion when immobile or suffocate marsh vegetation when mobile. Suffocation of vegetation can lead to the destabilization of the marsh platform due to waves being able to reach farther inland with no aboveground vegetation to dampen energy. The proposed work will build off existing work, examining how the ridges have changed through time. Land loss data will be compared to total area, length, and distribution of shell ridges to analyze if there is a trend, such as the presence of historic storm activity. One question this study hopes to answer is if there are any changes in shell ridge movement and/or erosion during cold front or tropical cyclone season. With this information the city of New Orleans and state of Louisiana will have a better understanding of the life expectancy of Biloxi marsh as it is the main buffer against storms.

Keywords: shell ridges, marsh edge erosion, Louisiana, cold front, tropical storm, saltwater marsh

CHAPTER 1. INTRODUCTION

The landscape of coastal Louisiana is dominated by the dynamics of the Mississippi River Delta (MRD). Louisiana has the third longest shoreline in the United States and is more than 11,000km long (Medeiros, 2020). Coastal Louisiana wetlands are part of the 7th largest delta complex on Earth and contain approximately 37% of the marshes in the United States (Couivillon, et al., 2011). The wetlands and salt-water marshes within Louisiana are a critical natural line of defense against relative sea level rise and storm of the mainland and coastal communities (Gramling et al., 2005). From 1932 to 2010 Louisiana wetlands lost 25% of the 1932 land area with 26.67km^2 lost per year between 1985 to 2010 (Couivillon, et al., 2011).

The high rate of erosion in the MRD system is in part caused by human actions and climate change including: relative sea level rise, dredging of ship channels and canals, construction of levees, dams, and roads, wave-induced erosion, and saltwater intrusion (Day et al., 2000; Gagliano et al,. 1981; Wilson and Allison, 2008; Couivillon et al., 2013). A deltaic system operates by depositing sediment from a river in amounts that generally allows for vertical accretion in the marshes that leads to an offset of the impacts of relative sea level rise, but this area is experiencing a lack of sediment deposition coupled with erosional events such as tropical cyclones and cold fronts.

1.1 Regional setting

The MRD is a large delta within the northern part of the Gulf of Mexico that has created wetlands and sandy barrier island environments in response to fluvial processes, and marine transgression. The Mississippi River system has been active since at least the Late Jurassic and during the Holocene (last ~10ky) has created the Mississippi River delta plain, which is one of the largest delta plains extending across 30,000km^2 (Coleman et al., 1998). The delta plain surface geomorphology and subsurface sedimentary architecture reflects a complex history of fluvial, deltaic, and marine sedimentary processes impacted by changes in relative sea-level and variations in sediment delivery to the north-central Gulf of Mexico (Kulp, et al., 2005) Human action in the MRD has disrupted the natural sediment and water dispersal processes (Roberts et al., 1998).

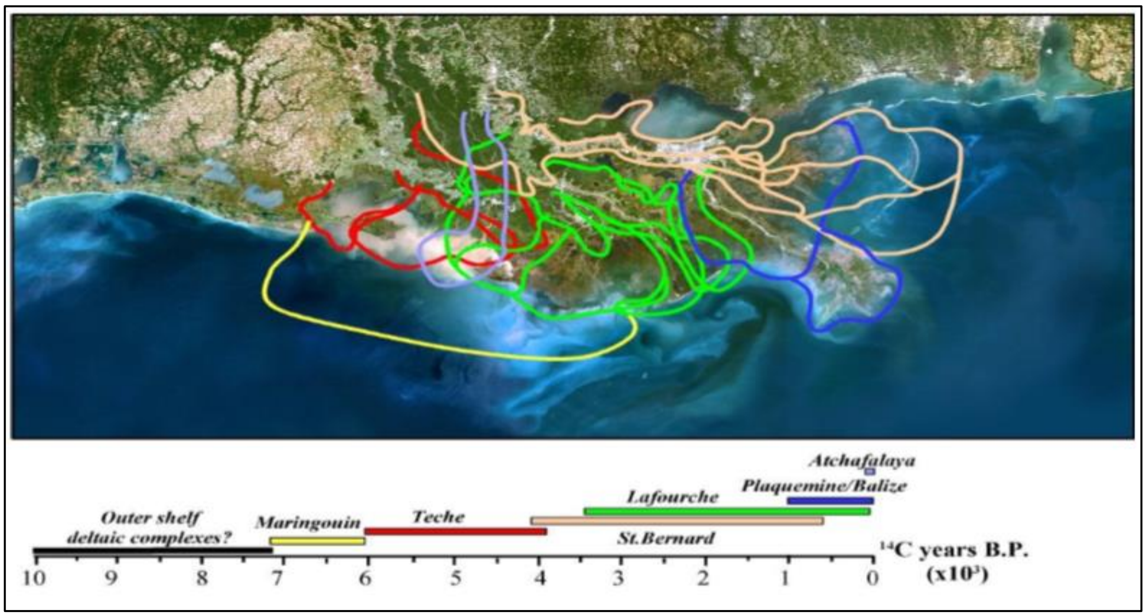


Figure 1: Map showing timing between delta complexes of the Mississippi River. The St. Bernard delta complex is shown in the east (tan color). From Kulp et al. (2005) modified from Frazier (1976).

Like many of the large deltas around the globe, the MRD is densely populated and there is substantial concern about relative sea-level rise (RSLR), coastal erosion and wetland loss (Törnqvist et al., 2006). The MRD is a low annual wave, tidal and current energy environment making it one of the best examples of a river-dominated delta (Roberts, 1997). The MRD distributaries changed their geographic position approximately every 1000-2000 years during the Holocene forming a new delta complex each time (Coleman et al., 1998). Each delta complex has sub deltas, bay fills and crevasse splays that operate at higher frequency temporal periods of a few hundred years to a few decades (Coleman et al., 1998). The overall result of delta building events are low lying landscapes with areas that are building and deteriorating all at different rates (Coleman et al., 1998). The MRD and surrounding wetlands are recognized as direct or indirect results of cyclic delta-building events (Roberts, 1997).

There are six Holocene delta complexes recognized: the Maringuoin, the Teche, the St. Bernard, the Lafourche, the modern Plaquemines that is also known as the "bird-foot" delta, with the Atchafalaya as the newest and a result of the Atchafalaya River diversion (Fig. 1) (Coleman et al., 1998). When the river diverts the resulting delta evolves in a semi predictable and a systematic set of stages (Coleman et al., 1998). The stages are as follows: (a) rapid progradation with increasing-to-stable discharge, (b) relative stability during initial stages of waning discharge, (c) abandonment by the river in favor of a higher gradient course to the receiving basin, and (d) marine reworking of a sediment-starved delt a as it undergoes progressive submergence as a result of sediment starvation and relative sea level rise (Coleman et al., 1998).

Within the St. Bernard delta complex is the Miss – La Loutre lobe shown in figure 1. The Biloxi marsh, as part of the St. Bernard delta complex, is dominated by *Spartina* *alterniflora* (Crawford, 2018). There is an absence of sand-rich shorelines throughout the Biloxi marsh and instead the primary autochthonous sediment is either whole or fragmented shell. The primary shells are *Crassostrea virginica* and *Rangia cuneata* (Crawford, 2018).

1.1.1 Biloxi Marsh

The St. Bernard delta lobes, shown in figure 1, became active at approximately 3.5ka during the Holocene (Roberts, 1997). The extent of the Biloxi marsh developed with the St. Bernard delta complex with a transition to full marsh platform at approximately 1.5ka after St. Bernard complex abandonment (Penland et al., 1988; Roberts, 1997). The Biloxi marsh undergoes erosion in two ways: interior and edge erosion (Ellison, 2011). Land loss is relatively low in the St. Bernard marsh (Couvillion et al., 2011) and a study by Wilson and Allison (2008) indicated that marsh edge erosion is the dominant form of Biloxi marsh erosion.

The Biloxi marsh is shown in figure 2. It is characterized by shorelines with non-mobile shell ridges that are more heavily vegetated with robust vegetation behind the ridges, whereas mobile ridges suffocate the marsh vegetation allowing waves to wash farther onshore due to lack of vegetation to dampen the wave energy (Crawford, 2018). Eventually, with sea level rise and storm activity the marshes are expected to erode, leaving behind subaqueous shell mounds (Ellison, 2011; Day and Templet, 1989; Mariotti et al., 2010).

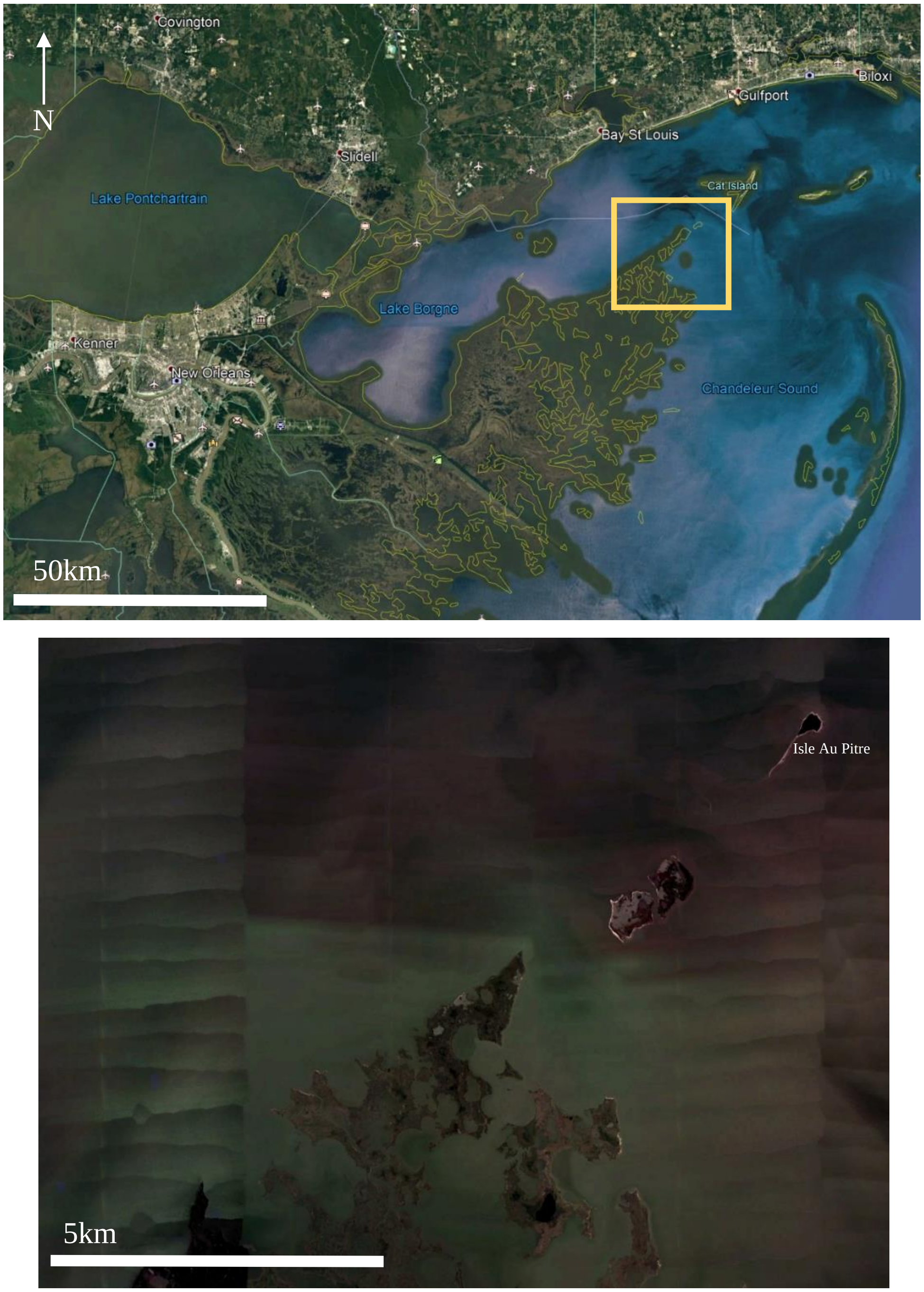


Figure 2: Google Earth base image of southeast Louisiana with a yellow box around Biloxi marsh and zoomed in image showing Isle Au Pitre's location within the marsh. Google Earth image dated 03/21/2019.

The future of the Biloxi marsh is uncertain, but it is expected to survive no more than 30 years under a "high" sea level rise scenario (figure 3.6 in the 2017 Coastal Master

Plan, CMP, main text) (Kemp and Day, 2017; CMP, 2017). The 2017 CMP is a multi-collaborative plan that sets a plan to respond to coastal land loss and the threats from storm surge events (CMP, 2017). The 2017 CMP lists projects that build or maintain and land or, reduce risk to communities (CMP, 2017). The 2017 CMP suggests sea level across the MRD rising by as much as 1.8m by 2100 (CMP, 2017). Kemp and Day (2017) commented on the 2017 CMP specifically covering the Biloxi Marsh Complex in terms of survivability, restoration, and sustainability. Since 2007, the CMPs have completed and/or funded 135 projects that have resulted in: more than 36,000 acres of land benefited, 454km of levee improvements, and more than 96km of barrier islands either constructed or under construction at the time of the 2017 CMP release (CMP, 2017).

Kemp and Day (2017) prepared comments on the 2017 CMP noting that the Biloxi Marsh Complex was only recommended for a few restorative measures to extend its lifespan past the projected 30-year mark. The marshes within the interior of the Biloxi Marsh complex differ from the eastern and western extents of the marsh mainly noting that the eastern marsh platforms are affected by sediment transported from Chandeleur Sound, whereas the western islands are supplied sediment by Lake Borgne (Kemp and Day, 2017). From the Coast Wide Monitoring System, it is calculated that the Biloxi Marsh Complex islands are accreting at rates from 0.7-1.7cm/yr and have a 0.6cm/yr in surface elevation change which supports Reed (2009) stating that "marsh soil development in the Biloxi marsh show that marshes there are sustainable now and should be well into the future" (Kemp and Day, 2017; King et al., 2006). Within the 2017 CMP the Integrated Compartment Model does not take in to account the shoreline retreat which is the primary cause of Biloxi Marsh Complex marsh loss (Kemp and Day 2017).

The purpose of this study is to gain a better understanding of the total distribution and extent of shell ridges and their role in the evolution of Isle Au Pitre of Biloxi marsh.

1.1.2 Study Site: Isle Au Pitre

Isle Au Pitre is the northeastern most island in Biloxi marsh. Previous work has been done on a neighboring island, Little Bayou Pierre. Isle Au Pitre was chosen as the study site for this project due to the island's continuous perimeter of shell mounded into ridges atop the marsh platform. In some areas on the southwest tip of the island there is no marsh platform visible under the shell accumulations. The wetland marsh area was classified as a saline marsh in 2019 by the Coastwide Reference Monitoring System (CRMS) dominated by *Spartina alterniflora* and *Juncus roemerianus* (lacoast.gov/crms_viewer/Map/CRMSViewer). Previous research done by Crawford (2018) on a nearby marsh island, Little Bayou Pierre, showed *Spartina alterniflora* was the dominate vegetation confirming the CRMS classification.

1.1.3 Gravel beach dynamics and shell ridges

Isle Au Pitre is a marsh island with little sandy sediment but with whole shells and shell hash that is the dominant material building shell ridges atop the marsh platform. Shell hash is in the size classification for gravel, specifically size classes granule to pebble ranging from 2-64mm, according to the Wentworth (1922) Grain Size Classification approach. Disk and blade-shaped particles/material tend to move up the beach with more ease than the spherical and roller-shaped particles under normal conditions (Bluck, 1967). The shell present at Isle Au Pitre is disk shaped and is either whole shell or shell hash in size and shape.

Natural and anthropogenic coastal features interacting with different forcing mechanisms such as wind, waves, and tides result in differing beach morphology that is constantly evolving (Medellín and Torres, 2019). Additionally, sediment properties, sediment supply, relative sea level change, wave dynamics, and topographic setting all impact the behavior of gravel-dominated shorelines (Orford et al., 2002). For example, a beach under storm conditions usually retains the larger sized sediment along the beach crest, whereas while larger and finer material is retained at the low water position (Orford et al., 2002). A return to fair weather conditions leads to coarser material left on the lower beach with the finer gravel material deposited farther onto the beach (Orford et al., 2002). Beach morphology gives insight on processes controlling sediment transport seasonally in beaches (Medellín and Torres, 2019; Orford et al., 2002) and may have application to the development of shell berms on marsh platforms

For berm building, Duncan (1964) observed that larger foreshore sediments tend to move onshore and form berms, whereas finer material is retained farther down gradient. Bushcombe and Masselink (2006) concluded that the growth of a berm requires onshore sediment transport, a foreshore-advecting tidal regime (infiltration losses at the landward extremities of run-up), and a specific sequence of swash excursion distances (too many large swashes would overtop and erode the berm, too many small swashes would not reach the berm at all).

1.2 Study Objectives

The objectives of this study are to answer the following:

1) How does the extent and distribution of shell ridges vary across Isle Au Pitre of Biloxi marsh during the time frame of this project?
2) Is there any change in shell ridge movement and/or erosion during cold front or tropical cyclones?
3) Do mobile shell ridges impact the marsh more quickly than non-mobile shell ridges?

CHAPTER 2. METHODS

2.1 Marsh Island Selection

Isle Au Pitre has continuous shell ridges visible on satellite imagery that appear as thick grey features that extend parallel to the island edges and can be seen in figure 2. These were assumed to be shell ridges, but confirmation needed to be done before selecting a specific study site. The observation of presumed shell on Google Earth and National Agriculture Imagery Program (NAIP) imagery was confirmed as shell ridges during a site visit in November 2019 (figure 3a). The island was split into two sections that will be referred to as “main island” and “tail section” (fig. 3b). The island has continuous shell ridges around the perimeter of the main section of the island atop the marsh platform. The tail section is composed entirely of shell hash and whole shell with very little to no marsh platform visible, whereas the main island has shell and or marsh platform at the water’s edge, shell ridges, and vegetation in the interior of the marsh.

The island was walked and analyzed on the November 2019 site visit. This was done to ensure the methods to measure the ridges could be completed in one day with travel time included. Due to the morphology and continuous shell ridges on the island it was decided to measure the ridges every 100m rather than select a dozen ridges. This was done due to the abundance of ridges on the main island. Transects on the tail were measured at different spacings than every 100m for each field visit due to the extreme morphologic differences and fragmentation of the tail section from field visit to field visit. The tail section has transects approximately every 20m. The tail section is analyzed at the start of every field day and the distance between transects on the tail is determined for that specific field day. Definitions of the 'main island' and 'tail section' can be found in figure 3.

Figure 3:**A**, photo from island showing grew perimeter shown in Google Earth imagery is confirmed shell and shell ridges. **B**, 2019 NAIP image in Arc GIS layer showing Isle Au Pitre with the January 15, 2020 data point locations shown as dots. The numbers near a string of data points is the specific transect number and the location of the transects on the "main island". The area of the red bracket is refering to the "tail section" of the island. The tail area is not numbered by transects.

2.2 Shell Ridge Measurements

A *Trimble R8s* is a Global Navigational Satellite System (GNSS) with a vertical and horizontal accuracy of +/- 0.25m + 1 ppm RMS and +/- 0.50m + 1 ppm RMS. This handheld system was used to trace the periphery of each shell ridge during successive field visits and was used to establish location data along the transects. The shell ridges rim the entire perimeter of the island. A transect was marked on the main island every 100m. The transect locations were saved on a handheld Garmin GPS with an accuracy of +/- 3m making the transect location data consistent on the main island for each field visit. Each shell ridge, along the specific transect, is measured with the *Trimble R8s*. The tail section has transect locations changing from during successive visits but the distance between transects is approximately 20m.

A total of 13 transects were established on the main island. The total number of transects ranged from 20-25 with the tail section of the island included. The island's morphology changed drastically during the study making it difficult to keep the number and location of transects consistent on the tail of the island (fig. 9 and 10). Tail transect locations are subaqueous at times, re-emerging at a later field date, or erode and turn into open water from one field visit to the next visit never reforming or reemerging. This creates a large inconsistency of transect numbers and transect locations. It was decided to treat the tail and main island separately in *Trimble R8s* data collection and data processing. The size of the tail section at the time of data collection determined the transect spacing. The number of data points within a transect varies for each data set to accurately describe each individual ridge at each transect. For example, where there are multiple, strikealigned shell ridges additional points were taken to capture such variability relative to a location with just a single shell ridge. The ridges are never the same morphologically from one field visit to the next.

Each transect was measured differently due to the differing morphology and extent. Three data points were taken at every transect and during every field visit. Along any given transect data points were taken at the water's edge (marsh/water line), shell line, and vegetation line. The water edge is defined as where the water meets the island at the shoreline. The shell line is where the shell started along the transect, whether it be at the water edge or inland atop the marsh platform. The vegetation line is where the shell stopped, and the vegetation began in the interior of the marsh. All data points that are taken are recorded in a notebook for every transect during every field visit. The written record allows for there to be a record of what the data points represent (water line, shell line, increase in slope on ridge, decrease in slope on ridge, crest of ridge, and vegetation line). Photos were taken at every transect to go along with the notes and *Trimble* point data.

Photos were taken at each transect during each field day to compare to one another providing a visual record of the shell ridge transects through time. PVC pipes were driven into the marsh at four transect sites, totaling eight PVC pipes, on February 3, 2020 to better track the shell ridge movement visually. Photographs were taken at every PVC pipe to compare overtime and provide a digital record of the ridges. The pipes did not make it through the long five-month break in field visits due to COVID-19 and therefore produced no data.

Despite the many obstacles of COVID-19, schedule conflicts, and storms creating unsafe marine conditions a total of eight field visits were completed in 2020 with data collected seven of those field visits with dates shown in table 1.

2.3 Polygons and Data Points

Trimble Business Center (TBC) has many functions. For processing the GPS data was imported from the handheld device used in the field and the settings were adjusted for the correct UTM zone. Data points were then connected to create polygons according to the field notes. For example, all main island water line data points are connected to create a polygon for the water line. This was done for the shell line and the vegetation line on the main island. This produced a total of three polygons for every field visit. This was done for the tail section (kept separate from main island) but only for the water line due to the lack of vegetation on the tail section. The water line is also the location of the shell line at every transect on the tail. This creates one polygon per data sat for the tail section. Creating polygons allows TBC to calculate area, line length, maximum and minimum heights along the polygon line, and much more that is not used for this data. With all the necessary data points connected into polygons from each data set, the data is exported as a shapefile. The shapefile is imported into ArcGIS and overlaid on the NAIP 2019 imagery.

2.3.1 Water, Shell, and Vegetation Line Movement

The shell ridges varied from transect to transect and field visit to field visit in location, morphology, extent, and visual appearance. Transects 1-13 were monitored while the transects on the tail were not monitored by location but by the ability to measure the tail due to its drastic morphological changes. Height measurements were not recorded for two of the seven field visits inhibiting volume calculations. Area, rate of change in terms of meters per day, and water/shell/vegetation line movement were calculated for all seven data sets. The polygons in ArcGIS give a bird's eye view of the retreat of the vegetation line and the overall vegetation area and marsh area land loss (fig. 13).

The ArcGIS "measure" tool was used to measure the marsh edge retreat or advancement from one data set to the next in chronological order. This was done by color coding two data sets. In figure 8 there are two data sets shown in yellow and purple. September 1 is purple, and October 13 is yellow. The figure shows that from September to October the water line prograded, thus showing as a land gain and as a positive value.

This marsh edge is recorded as a (+) value in the graphs, whereas a marsh edge retreat is shown as a (-) value. This is done for every transect and every data set as follows: Jan 15 to Feb 3, Feb 3 to Feb 17, Feb 17 to Mar 12, Mar 12 to Aug 18, Aug 18 to Sept 1, Sept 1 to Oct 13. The marsh line/water line, shell line, and vegetation line movement were all calculated using this method. The water line can also be called the marsh line if the marsh is present at the water line, if no marsh is present it is referred to as the water line. Imagery from NAIP is obtained for the year 2019. It is made apparent early on that the NAIP 2019 Imagery was the closest to the shape and size of the current state of the island through this project and is therefore used for illustrative purposes here.

2.4 Characterizing Storms and Field Work Conflicts

Marine conditions during the fall and winter months of this project were very unstable and it was difficult to predict when field work could be completed safely. The fall of 2020 was an extremely active tropical cyclone season and after Hurricane Zeta (fig. 5) it was decided that field work would end in order to complete the project in a timely fashion.

Cold Fronts:

Louisiana coastlines can experience 30-40 cold fronts a year between October and April months (Moeller et al., 1993). Prior to a winter cold front strong south winds can exist but after a cold front pass's winds shift and flow from the north, which in turn drives down water levels and dampens onshore wave action in coastal area (Moeller et al., 1993). Coastal waters will also cool during this transition and water levels continue to drop allowing marsh drainage and bay waters to discharge into surrounding bays and the open Gulf of Mexico (Moeller et al., 1993).

Cold fronts are defined as: "A zone separating two air masses, of which the cooler, denser mass is advancing and replacing the warmer" from the National Weather Service (fig. 4). As a cold front approaches the local water levels can elevate as much as 1m. The passage of a front has the maximum wave variability and wave energy occurring than at any other point of the cold front (Guo & Subrahmanyam, 2020). Due to the high frequency of occurrence, large area of coverage, and persistent system of wind direction shifts of approach are all hypothesized to be affecting coastal environments more than occasional tropical storms (Moeller et al., 1993).

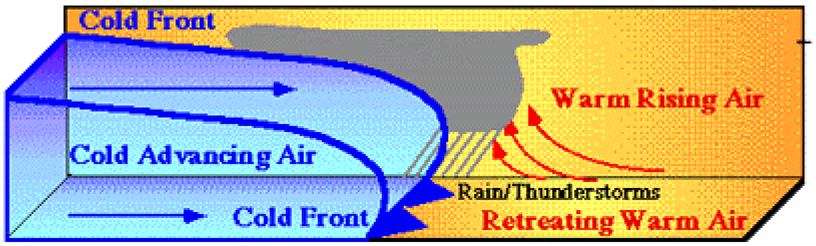


Figure 4: "This vertical cross-section of a cold front shows cold air behind the cold front (dark blue lines) advancing into warmer air ahead of the front. Where the two air masses meet, convergence often occurs which can result in upward motion of air parcels. If the air contains enough moisture, rain can occur. If the air also is unstable, thunderstorms can develop as well. This is a simplified view of a cold front. Sometimes, fronts aloft (above the surface) can result in precipitation ahead of cold fronts." From the National Weather Service (University of Illinois).

Tropical Cyclones:

The state of Louisiana was in the tropical cyclone cone of uncertainty numerous times in 2020 with five tropical cyclones making Louisiana landfall and nine tropical cyclones entering the Gulf of Mexico. All 2020 Gulf of Mexico tropical cyclones are shown in figure 5. Every time New Orleans was in the cone of landfall uncertainty there was no field work conducted for safety reasons. Hurricane Cristobal did not impact this research due to COVID-19 restrictions already halting field work. Hurricane Marco, Laura, Sally, Delta, and Zeta all halted field visits due to unsafe marine conditions and safety of the university personnel because preparing to shelter in place or evacuate took precedent.

Tropical Cyclones are described in the following way: "*A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. Tropical cyclones rotate* *counterclockwise in the Northern Hemisphere"* (National Hurricane Center, 2020). They are classified as follows:

- Tropical Depression: A tropical cyclone with maximum sustained winds of 38mph (33 knots) or less.
- Tropical Storm: A tropical cyclone with maximum sustained winds of 39 to 73mph (34 to 63 knots).
- Hurricane: A tropical cyclone with maximum sustained winds of 74mph (64 knots) or higher. In the western North Pacific, hurricanes are called typhoons; similar storms in the Indian Ocean and South Pacific Ocean are called cyclones.
- Major Hurricane: A tropical cyclone with maximum sustained winds of 111mph (96 knots) or higher, corresponding to a Category 3, 4 or 5 on the Saffir-Simpson Hurricane Wind Scale." (National Hurricane Center, 2020).

Field Dates:	January 15, 2020	February 3, 2020
February 17, 2020	March 12, 2020	COVID-19 Shut Down
August 18, 2020	September 1, 2020	October 13, 2020

Table 1: Dates of field work with COVID-19 shutdowns included.

Southeast Louisiana was hit by Hurricane Zeta on October 28 as a category three storm at landfall and winds reaching 110mph. Power was out to two million residents for one week or longer in some areas, resulting in the cessation of field work once more. After Hurricane Zeta and tropical cyclone season ended and the Gulf of Mexico entered cold front season.

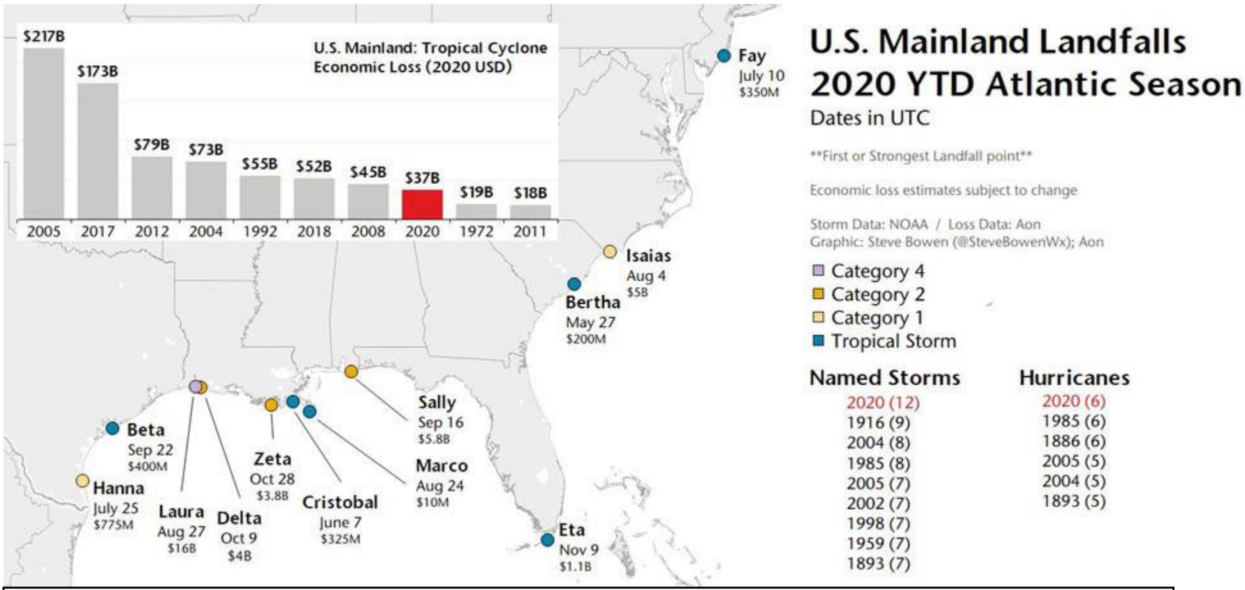


Figure 5: Map of the 2020 Gulf of Mexico hurricane season with economic impacts (Masters, 2020).

The COVID-19 virus impacted the University of New Orleans causing a shut-down mid-March 2020 until mid-August 2020. COVID-19 continued to restrict out of state travel by State employees until early 2021. The restriction on out of state travel strongly affected this project because this research site was easiest to travel to from a boat launch in Mississippi, with a travel duration of approximately 40 minutes one-way trip across open marine water. Using a new boat launch in Louisiana increased transit time to an hour and a half and sometimes longer depending on marine conditions. With these challenges, a total of seven field visits were completed.

CHAPTER 3. RESULTS

3.1 Shell Ridge Measurements

The total area of the main island was 99,512m^2 on January 15. The data collected on the last field day, October 13, indicated a total area of 78,832m^2. That is a 20,680m^2 decrease in main island total area. The area of vegetation, the center of the island that is behind the shell ridge, gradually decreased throughout the course of the research. The vegetation area started at 71,477m^2 on January 15 and decreased to 51,449m^2 on October 13. That is a 20,029m^2 decrease in main island vegetation area which is the only area not disturbed by shell or shell ridges. The main island area and the center vegetation area of the main island decreased almost the same amount of area from the first to the last field day. The tail section of the island was highly unstable and was disregarded in much of the data processing as a whole but was processed and analyzed as a separate unit from the main island. The tail section of the island had an area that was decreasing throughout the field visits. The tail section started with an area of 11,410m^2 on January 15 and ended with an area of 1,712m^2 on October 13. The area decreased a total of 9,698m^2.

Figure 6: Graphed data of the total area of the main island at shoreline, vegetation polygon on the main island, and the total area of the whole tail section excluding the main island area.

3.2 Marsh, Shell, Vegetation Line Retreat or Advancement

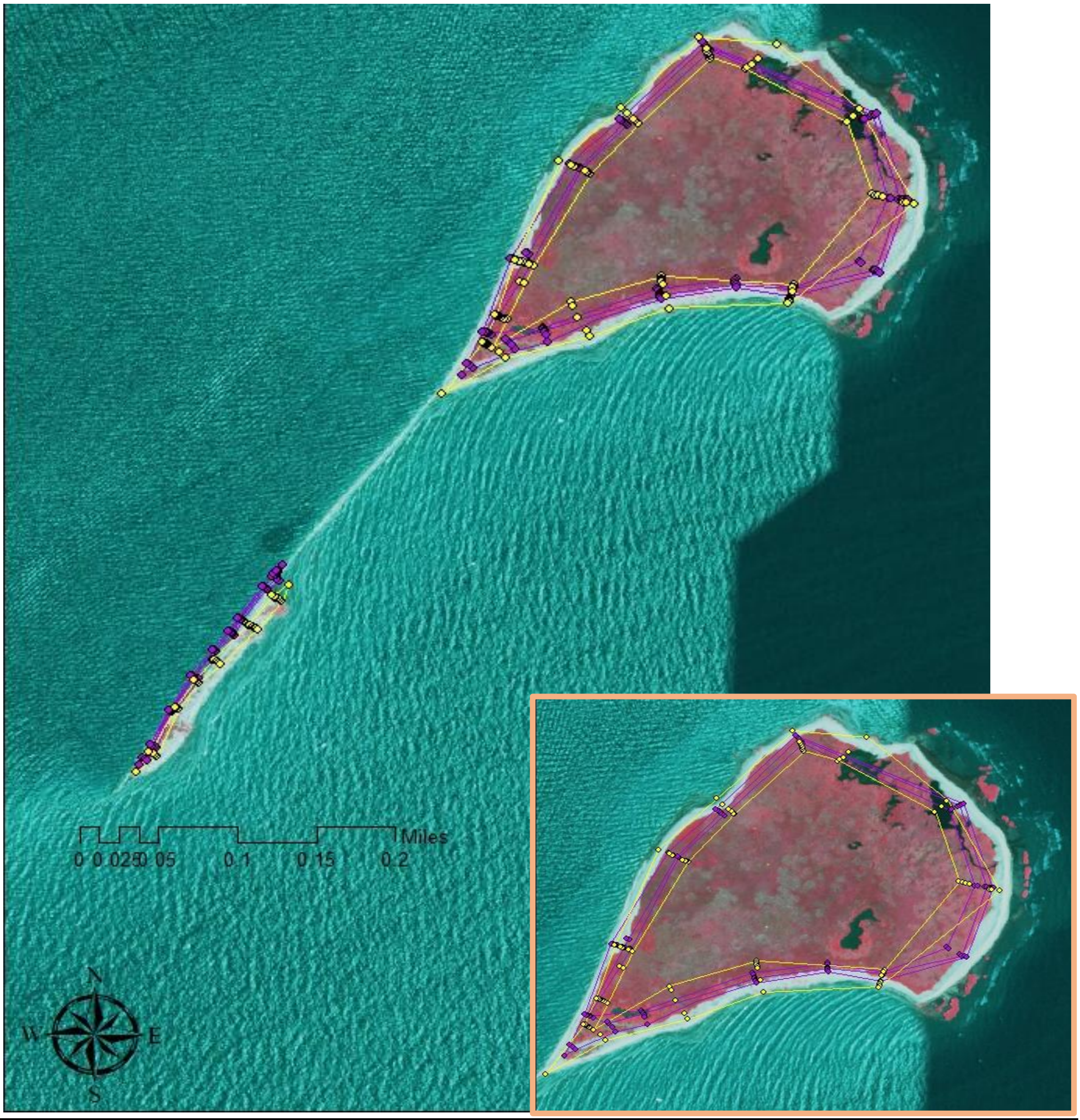


Figure 7: ArcGIS image of Isle Au Pitre using the 2019 NAIP image with September 1 and October 13, 2020 data as layers. The yellow polygon lines and data points are October 13, 2020 data and the purple polygon lines and data points are September 1, 2020 data. For each data set there may be 2-3 polygons. The outer polygon is the marsh line where the water meets the marsh edge (or shell ridge in cases where marsh platform is not exposed), middle polygon if there is one present is the highest point at each transect, and the inner polygon is the vegetation line where the shell ridge ends and vegetation (or interior ponding) begins. Image outlined in orange shows the main island data points and polygons zoomed in for a clearer picture. Note October 13, 2020 is missing transect data for transect #8.

Figure 8 shows October 13 and September 1 data with data points as well as polygons. The data points do not line up perfectly due to GPS accuracy of +/- 3m that was used to mark the transect location and was used every field visit to return to the transect locations. For the transect shown in figure 8, the marsh edge, or water line, advanced by approximately 28m. This shows in the graphs as a positive value (fig. 6). The eastern area of the main island routinely was submerged by a few centimeters of water one field visit but was exposed/above water level at the next field visit. This was documented by taking photos (fig. 16).

Figures 9, 10, 11, and 12 show images of the marsh island from different angles on every field visit. The 'tail' of the island was connected to the main island on January 15 and February 3 but every field visit after February 3 the 'tail' was separated by a body of water that became deep enough to be used as a channel for boats. The 'tail' was drastically different morphologically from visit to visit but also drastically different in geographic location. Sections would become submerged, reemerge at the next site visit, or would disappear altogether, or form new sections. Due to this, the 'tail' data was not considered except for the area measurements for the tail and not combined with the main island. March 12 there is an increase in total area (m^2) of the tail (fig. 6) and that is due to the tail having a second section that was likely created due to transport of shell hash from the area of the tail that separated changed to open water from the main island. After March 12 the second section of the tail, creating three total areas of land for Isle Au Pitre, never reemerged.

The marsh edge/water line at times was also the shell line (fig. 11 & 12). The imagery shows the water line from Sept 1 to Oct 13 located at different areas on the marsh platform, a difference of 7.9m, showing an erosional event in the graphs but is actually a water level fluctuation. Figures 13, 14 and 15 show NAIP imagery from 2019 with data sets overlaid that show water/marsh, shell, vegetation line movement. The vegetation line retreated into the center of the island with Jan 15, Feb 3, and Feb 17 grouping together showing an average movement of -0.1m from Jan 15 to Feb 17, then Aug 18 and Sept 1 move inland more drastically and stay grouped with an average movement of -1.1m from Sept 1 to Oct 13, and lastly the Oct 13 data set being the most inland for the vegetation line. The line that has the most movement is the vegetation line compared to the shell and marsh line of the main island. From Jan 15 to Oct 13 the vegetation line moved an average of -2.9m, the shell lined moved an average of -2.0m, and the marsh/water line moved an average of -2.5m. This is decreasing the interior vegetated area of the marsh not yet covered or impacted by loose shell or shell ridges.

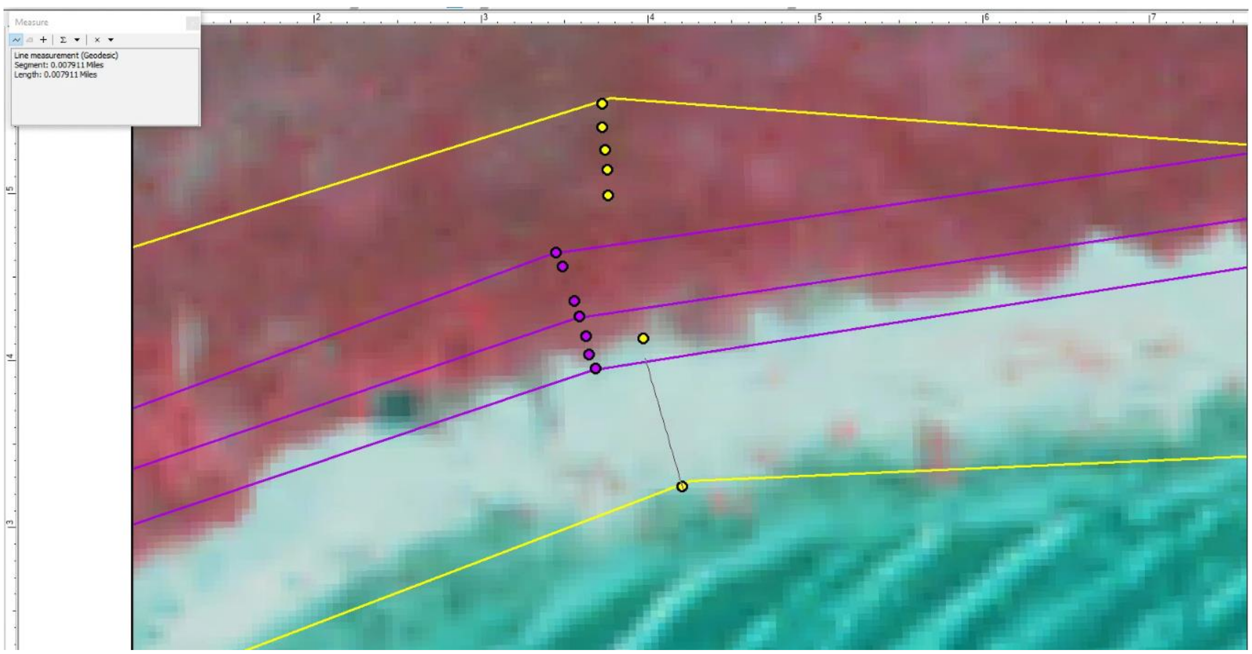
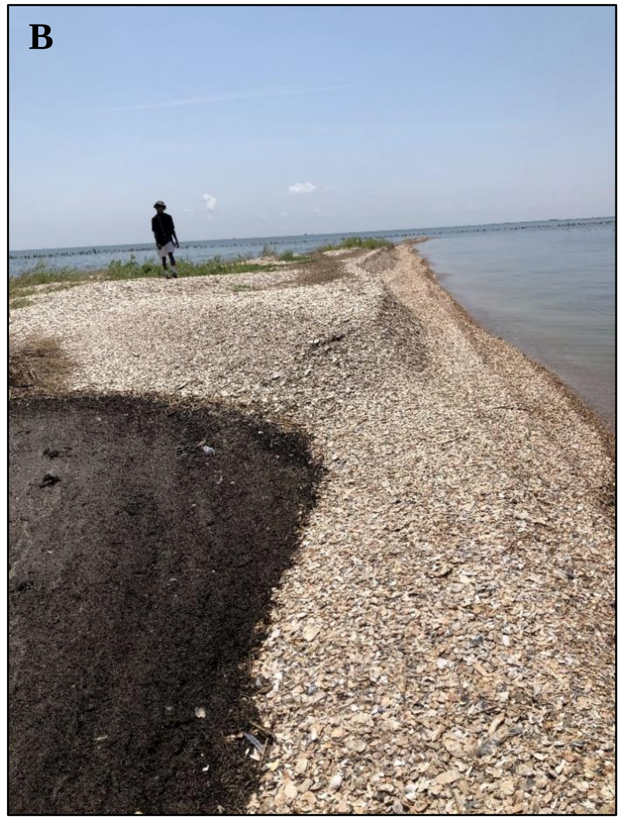


Figure 8: Zoomed in image of transect 6 with September 1 data shown in purple and October 13 data shown in yellow. The grey line represents the line created by using ArcGIS's measure tool. This shows the water line 'advancing' seaward from Sept 1 to Oct 13.

Figure 9: Images from the main island looking down the 'tail' of the island. Note, Feb 3's view is from the tail to the main island. Top right image is index image with the star representing near where the photos were taken and the arrow pointing in the direction the photos were taken (except Feb 3).

Figure 10: Images from the main island looking down the 'tail' of the island. Top right image is index image with the star representing near where the photos were taken and the arrow pointing in the direction the photos were taken.

Figure 11: Location is transect 8 looking south west towards the tail, eastern side of island. **Photo A**, Sept 1 field date. Note the water line touching the shell line. **Photo B**, Oct 13 field date. Note the water line farther out and touching the brown marsh platform not the shell line.



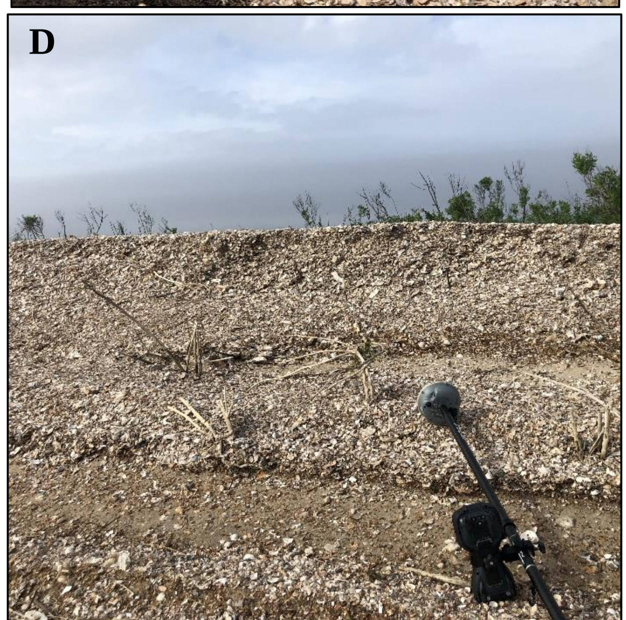


Figure 12: Transect 3 area viewing towards the 'tail' section.
A is 3/12, B is 8/18, C is 10/13, and D is scarping of the shell ridge on 1/15.

Figure 13: ArcGIS image showing the vegetation polygon for all data sets except 3/12. The data is overlaid on NAIP 2019 imagery.

Figure 14: ArcGIS image showing the shoreline polygon for all data sets except 3/12. The data is overlaid on NAIP 2019 imagery.

Figure 15: ArcGIS image showing the shell line polygon for all data sets except 3/12. The data is overlaid on NAIP 2019 imagery.

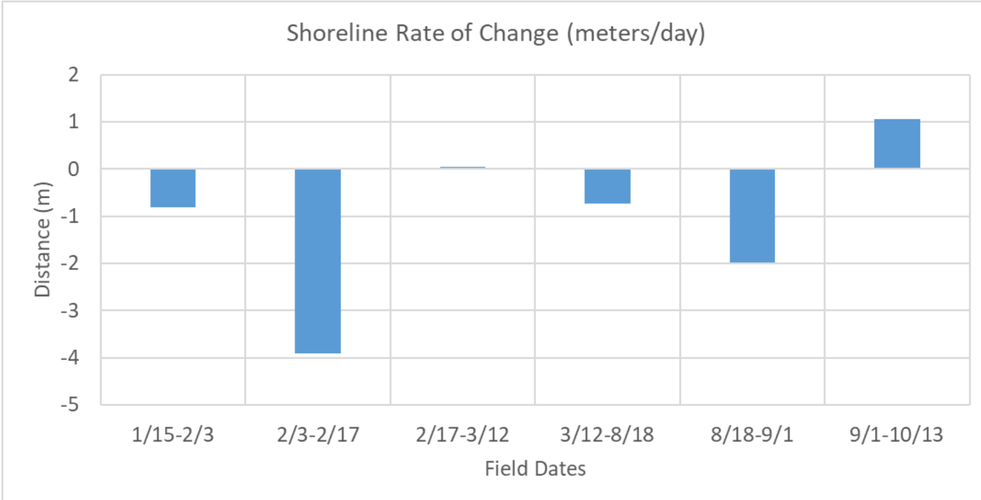
Figure 16: Image A at transect 5 looking northeast on field date 2/3. Image B at transect 5 looking northeast on field date 2/17. Images taken at slightly different locations but aids in the visualization of the marsh on the eastern side when the shoreline location changes drastically due to water level fluctuations. The shoreline/marsh line data point is taken where the water touched the marsh at each field visit. This water level fluctuation shows on graphs as shoreline 'retreat' of many meters but is the submergence and reemergence of the marsh platform on the eastern side of the island.

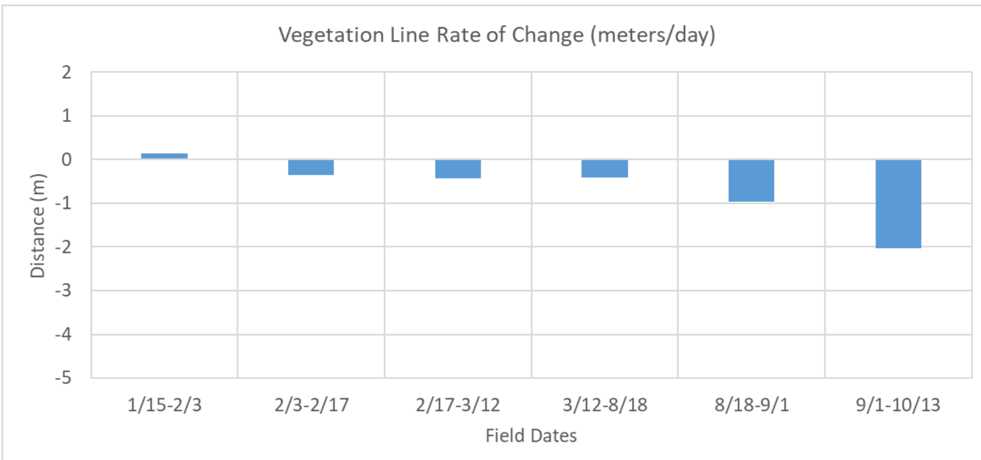
3.2.1 Rate of Change

The water, shell, and vegetation lines from all field visit dates were collected and processed as explained previously. Figure 17 shows the normalized results as rate of change (meter/day) for the whole of the main island and not individual main island transects. Most lines retreated to the interior of the marsh island. The distance the shell lines moved ranged from retreating 17.4m and advancing 9.6m. The shoreline was measured to have retreated 13.3m from February 3 to February 17 at transect 5 on the eastern side. Note figure 16 showing the water's edge located farther inland on February 17 than February 3. A 10.0m retreat was measured on the eastern side at transect 8 from field visit February 3 to February 17, too (fig. 16). The distance the water line/marsh edge moved ranged from retreating 28.1m and advancing 9.7m.

From March 12 to August 18 the water, shell, and vegetation lines retreated, most of the lines retreated from August 18 to September 1, a few lines advanced during January 15 to February 3 and February 3 to February 17 as well as February 17 to March 12. From September 1 to October 13 the lines varied in movement the most with almost every marsh line advancing, half the shell lines advancing, but all the vegetation lines retreating. The advancement recorded from September 1 to October 13 was likely due to tidal fluctuations. Figure 20 shows marsh platform submerged that was not submerged the entirety of the research period and would reemerge when water levels were low. Figure 16 shows a similar situation of fluctuating water levels giving very large 'false' retreat results of the shoreline. This was true in terms of advancement as well.

The 2020 tropical cyclone season began shortly after the COVID-19 shutdowns, between field dates March 12 and August 18. This area experienced nine storms with seven of the tropical cyclones and tropical storms impacting Louisiana. Late summer and early winter 2020 this area started to experience cold fronts. Storm activity, frequency, magnitude and dominant wind directions and average wind speeds are considered. Winds change by the season and storm activity varies year by year (figure 19). For 2020, the wind directions were N-NE for 2019 into 2020 winter, S-SE for spring 2020, W-SW-SSW and SE-SEE for summer 2020, and NE-NEE-E for fall 2020 shown in figure 19 (IEM 2020).





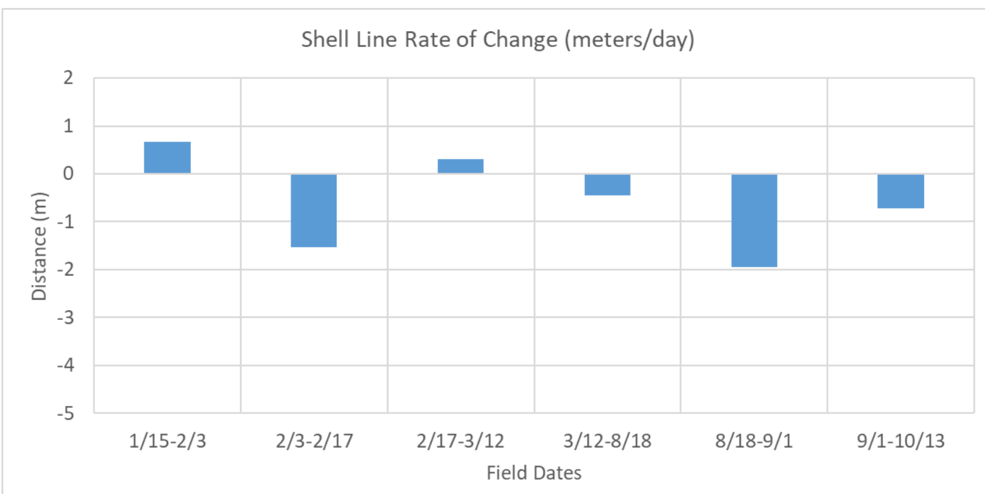


Figure 17: Graphs showing rate of change for shoreline, shell line, and vegetation line (m/day). Lines previously defined. Negative values represent retreat/movement towards interior of island and positive values represent advancement/seaward movement.

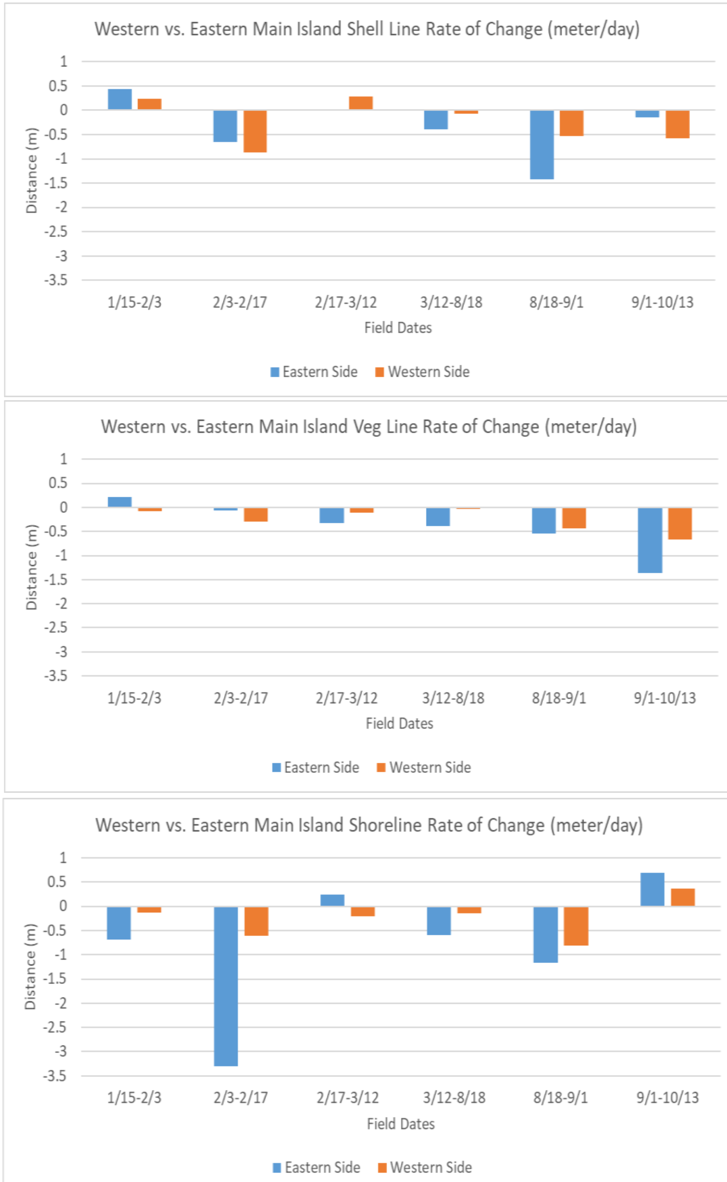


Figure 18: Graphs showing rate of change for shoreline, shell line, and vegetation line (m/day). Lines previously defined. Negative values represent retreat/movement towards interior of island and positive values represent advancement/seaward movement. Eastern side is defined as transects 4-10 and the western side 1-3 and 11-13. Main island only.

3.3 Storm data

The Coast Wide Monitoring System (CRMS)was designed to monitor effectiveness of restoration efforts at multiple spatial scales from an individual project to the influence of multiple projects on the entire coast of Louisiana. The CRMS network allows for comparisons of changing conditions at CRMS sites and was used for this research due to the proximity of some sites to Isle au Pitre.

Iowa State University's Iowa Environmental Mesonet (IEM) manages and collects data from cooperating members with observing networks. Wind roses shown in figure 19 are from the station named "Mississippi Sound at Grand Pass" with the code: GRPL1 from network: LA_DCP. Wind directions primary coming from the north during winter months, the south during the spring months, the south west and south east during the summer months and from the east during the fall months. The data was not further broken down due to the almost year long duration of research. 20+ mph winds were recorded more often during the winter and fall months, which could be correlated to cold fronts that are common for this area during those seasons. Figure 19 shows dominate wind direction the area experienced in 2020 broken up by seasons.

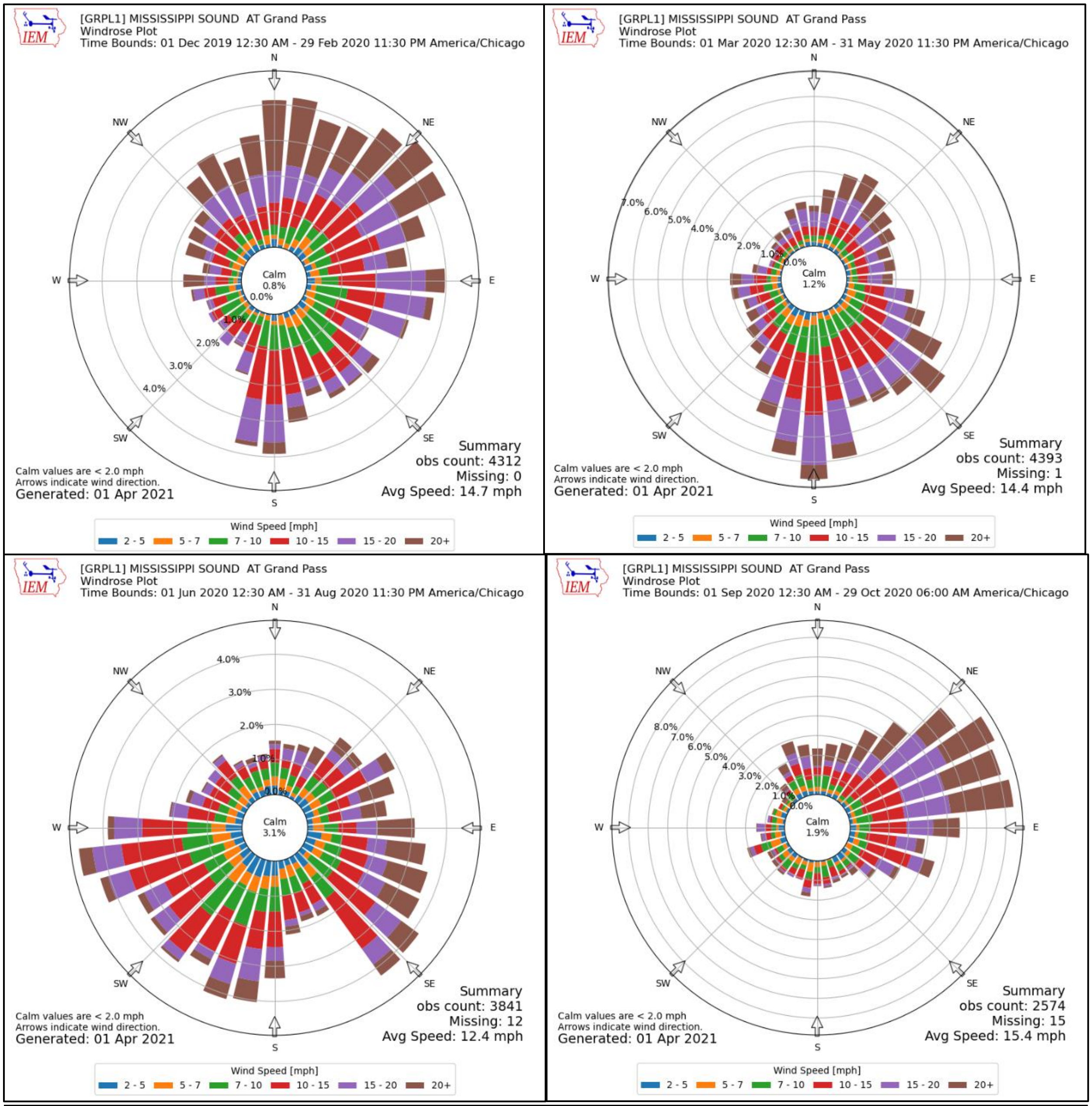


Figure 19: Wind roses from Iowa State University's Iowa Environmental Mesonet (IEM). The data is stored and made available on their website at https://mesonet.agron.iastate.edu/ where wind roses are available. The wind roses are broken up into seasons starting with winter 2019/2020, spring 2020, summer 2020, and fall 2020 presented in a clockwise orientation.

CHAPTER 4. DISCUSSION

4.1 Water, Shell, and Vegetation Line Movement

Isle Au Pitre has a continuous accumulation of shell around the perimeter of the marsh island with marsh platform exposed or subaqueous shell ridges constituting the shoreline/marsh edge rather than sand-rich shorelines. The main part of the island is more stable than the tail part of the island in terms of shell ridge movement, overall island morphology, and shell ridge morphology. The tail is composed entirely of shell as the sediment and with very little to no marsh platform exposed.

The eastern side of the main island has far more low lying, sloping, marsh platform exposed at the water's edge than the western side. This makes the shoreline data points change up to 10's of meters, which can show up in the data as large erosional or land building events. The water level impacted the data but can be explained through photo record. The eastern side's shoreline measurements from February 3 to February 17 at transects five and eight have retreats of -13.3m and -10.0m. Figure 16 shows that the large retreat at transects five and eight from 2/3 to 2/17 is largely due to a lower water level on February 3 and higher level on February 17 and is not a reflection of marsh erosion.

The opposite occurred from September 1 to October 13 with the shoreline showing large amounts of advancement. Photos show the shoreline (fig. 11) more submerged on September 1 with more marsh platform exposed on October 13 giving a positive value of edge advancement and not land building (fig. 17). Overtime, the water, shell, and vegetation lines all retreated inland even with the few positive values (figure 17 and 18). The shell ridges are moving inland and in doing so the interior vegetation is becoming suffocated and leaving behind exposed and non-vegetated marsh platform. As long as the shell ridges are mobile and translating inland the island is losing interior marsh vegetated area and experiencing erosion on the marsh edge.

4.1.1 Storm Impacts, Tides, and Water Level

The tidal range for this region is a microtidal environment. Figure 11/16/20 shows the marsh edge morphology as well as the cm scale submergence the marsh platform undergoes from water level fluctuations. This should be noted for figure 17 where the marsh edge is shown with positive values. The marsh island did not show areas where the edge was actively building out to give the positive values shown in figure 17. Instead, what was occurring is what figure 11, 16, and 20 shows, which is minor tidal action on the already low-lying marsh platform edge.

Tropical cyclones and cold fronts can produce water levels and wave energy that can overtop marshes in Louisiana (Reed, 1989b; Dietrich, 2011). Crawford (2018) discussed that at her Biloxi marsh site the largest shell ridge cross-marsh translation occurred after Hurricane Nate made landfall on October 7, 2017. The amount of movement was measured as 20.6m of inland movement (Crawford, 2018). Thomason (2016) conducted a two-year study on a nearby site concluded that the most movement shell ridges underwent occurred during and immediately after an extratropical cyclone event. Watzke (2004) concluded that cold fronts are just as important as tropical storms when looking at the processes impacting shoreline change. Survey profiles show that a winter season with numerous cold fronts passing causes an equivalent amount of erosion on shorelines as a single tropical storm (Watzke, 2004). During this thesis research there were many cold fronts and tropical cyclones that impacted Biloxi Marsh. To add, there is a five-month gap in field work due to COVID-19 with the field date before shutdown shortly after March 12 and the first day back on August 18.

The most line movement occurred from March 12 to August 18 with water, shell, and vegetation lines all retreating towards the interior of the marsh island. Figures 13, 14, and 15 show movement overtime but with March 12 data exempt. The data is not included due to three transects that experienced equipment malfunctions. Regardless of missing three transects the other transect data from March 12 to August 18 shows the most line movement for all three polygon lines. The most movement measured from March 12 to August 18 is as follows: marsh line moved the least at transect six with a movement of -6.2m and moved the most at transect nine with a movement of-28.1m, the shell line moved the least at transect six with a movement of -3.4m and moved the most at transect nine with a movement of -14.4m, the vegetation line moved the least at transect seven with a movement of -2.0m and moved the most at transect eight with a movement of -16.1m.

Photo records show the marsh edge eroding in figure 12 from 3/12 to 8/18. This is due mostly to the large gap in data and the active tropical cyclone season that occurred during the gap in data.

The five-month gap in data from the March date to the August date had nine tropical storms that impacted the Gulf of Mexico. Six of the nine storms made landfall on the Louisiana coast or dodging Louisiana at the last moment and making landfall on the coasts of the surrounding states. The large gap in data from March 12 to August 18 was unavoidable due to COVID-19. The most line movement, for all three lines, occurred during this time likely due to the large gap in field visits and the increased storm activity due to an active tropical cyclone season. The other data sets are compared with a 14-42day interval unlike the March 12 to August 18 field visits with a 159-day gap.

Water level changes impact the marsh and the data, photos in figures 11 and 16 show the water level fluctuations, but erosion occurred. Water level fluctuates during storm activity and from the microtidal cycle the Gulf of Mexico experiences. Figure 12b shows loose brown colored marsh sediment that was eroded and placed atop the marsh on loose shell from wave activity as well as submerged marsh platform that is also shown in figure 16. Figure 12 shows that from the start of the fieldwork that the marsh edge was exposed and had unique morphology, shown in the shoreline curvature of marsh platform with shell on top, but by the end of field work the marsh platform is no longer exposed and has a straighter shoreline composed of shell instead of marsh platform. While storms and tides caused the water level to fluctuate, the amount of fluctuation and impact on data was minimal because the photography confirms the water level fluctuations. Photos of transects from each visit allowed the data to be processed and assessed to confidently state that large values of advancement or retreat is explained as true retreat/advancement or water level fluctuations.

Understanding the wave power Isle Au Pitre is subjected to and wave transformation processes was important for this study. Isle Au Pitre is a small island with no islands or shorelines nearby to break up the wave activity. Due to the location of the island wave power equations were done by using meteorological data from the National Oceanic and Atmospheric Administration. Wind direction, wind speed, and wave height data was collected from NOAA buoys. The data had to be collected every hour, so each date had 24 entries. The data was input into Lakes Environmental software and the frequency distribution was produced. The frequency distribution data was then input into *Excel* to calculate the wave power. Isle Au Pitre has many buoys surrounding it and they were all calculated to compare to each other to ensure the wave power results were similar.

Isle Au Pitre experienced typical wave power during the study year of 2020. Figures 17 and 18 show no indication that seasonality greatly impacted the shoreline, shell line, and vegetation line movement. Suggesting that the wave power does not fluctuate enough during different seasons to be considered a factor but that water level fluctuations impact the data as photos have shown.

4.1.2 Rate of Change

The interior vegetated area of the marsh, not covered by shell, started with a total area of 71,477.6m^2 on Jan 15 and ended with a total area of 51,449.2m^2 on Oct 13. This is a loss of 20,028.4m^2 of total interior vegetated area over the course of approximately nine months. During the same time frames the shoreline retreated causing total marsh island land loss. From Jan 15 to Oct 13 the marsh island lost 20,680m^2 of total marsh island area. This loss of total marsh island area is supported by the interior vegetated area of the marsh losing land area also suggesting the shell ridges are moving into the interior of the marsh covering interior vegetation from wind and wave action. Figure 17 shows rate of change for all three lines on the main island showing that the shell line retreat rates correlate with shoreline retreat rates.

The shoreline and shell line retreat rates correlation were observed in the field where the shoreline was also considered the shell line in some areas. This is shown in figure 16 where the water line is touching marsh platform on Feb 3 but on Feb 17 the water line is touching the base of the shell ridge. Where the shoreline advances or retreats, the shell line moves in the same direction. The shell ridges are only observed moving inland, the shell line advanced Jan 15 to Feb 3 and Feb 7 to Mar 12 likely due to the small-scale water level fluctuations. Figure 12 shows how water level fluctuations and erosion can change the shoreline and shell line appearance from having marsh platform be exposed with the shell line beginning inland on Mar 12 to the marsh platform not visible and the shoreline having a straighter appearance on Aug 18. The water level rises and falls slightly and erodes the marsh platform and reworks the shell atop the platform to give slight variances in the shell line location showing small scale advancement. Figure 12b shows the eroded marsh edge (brown sediment atop the shell ridge in bottom left corner of image).

Figure 13 shows the vegetation line for each data set except Mar 12 due to missing transects from equipment malfunction. Data sets Jan 15, Feb 03, and Feb 17 are all very similar to each other geographically and overlap in many places, then Aug 18 and Sept 01 vegetation lines move inland but these two polygons overlap quite a bit, lastly Oct 13's vegetation line is the most inland. This is showing constant movement of the vegetation line inland overtime causing less and less interior vegetated marsh area. Figures 13, 14 and 15 show the most movement occurring on the eastern side of the island facing the open ocean with less movement on the western side facing Mississippi. Figure 18 shows most of the line movement occurring on the eastern side rather than the western side too.

The marsh island losing land area and the interior vegetated part of the main island losing area supports previous work done by Wilson and Allison (2008), Ellison (2011), and Crawford (2018). The shell ridges are moving to the interior of the marsh through time covering the vegetation leading to suffocation of the vegetation that will lead to destabilizing of the marsh edge causing marsh edge erosion as shown in figure 21.

4.2 Shell Ridge Effects on Marsh

Figure 20: In between transect 2 and 3 on 3/12/2020 for image B and 8/18/2020 for image A. Image A shows the marsh platform at the water's edge eroding due to wave activity. The marsh platform is a sawdust consistency in the water. Image B shows the bigger picture of the area to show the shoreline's morphology.

The *Trimble R8s* data points from each transect during the course of this study show that the shell ridges were continuously mobile. Previous work done by Crawford (2018) found that shell ridges do have a lasting effect on the marsh platform, affecting the lack of aboveground biomass present in front and below the shell ridges (Crawford, 2018). This means that where ridges are mobile and move inland, as they move the vegetation becomes smothered and dies leaving little to no aboveground vegetation in front of the ridges near the water's edge (Crawford, 2018). With little to no above ground vegetation near the water's edge leads to there being nothing present to dampen wave energy (Méndez et al., 1999; Méndez and Losada, 2004).

The most mobile shell ridges were on the eastern side of the island and the ridges that were less mobile were on the western side facing the Mississippi and Louisiana coastlines. The ridges that were more mobile were located on the sections of the island that experienced the most marsh edge retreat, which is the whole eastern side of the island. The eastern side of the island is exposed to large fetch conditions as it is facing S SE towards the open ocean. This means that fetch, wave energy, contributed significantly to the inland retreat of lines on the eastern side.

Figure 18 shows shoreline, shell line, and vegetation line movement for the eastern and western sides. Overall, the water, shell, and vegetation lines all retreated more than they advanced. This means the water, shell and vegetation lines are all retreating into the interior of most of the time from field visit to field visit. This is caused by the shell ridge rolling over into the interior of the marsh vegetation causing land loss of the interior vegetated section of the main island. The same is true for the tail section's water line retreating majority of the time. Crawford (2018) adapted the model from Ellison (2011) and Wilson and Allison (2008) to show this process in figure 21. The shell ridges, as they move inland cause loss of total marsh area and undergo a retreating shoreline.

All the shell ridges were mobile throughout the research but in different directions (advancing or retreating) and at different rates. With all the ridges considered mobile over the course of study the marsh was impacted negatively at every transect with no land gain and only land loss with water level fluctuations showing advancement being excluded as it is not land building. Crawford (2018) and Thomason (2016) concluded that shell ridges impact the marsh negatively and that larger fetch or more intense storm conditions are main contributors to shell ridge mobility. This leads to marsh edge erosion and thus, total marsh island erosion leaving behind subaqueous shell mounds. Where the ridges are more stable is where the marsh island will remain more stable (Crawford, 2018). This is because they are not affected by the wave and tide energy enough to move shell material inland and smother interior vegetation.

Figure 21 shows a marsh edge with above and below ground vegetation or biomass, slight erosion occurring that deposits the eroded marsh atop the marsh edge, shell being excavated and placed atop the marsh as well, then the shell either continues to grow into a tall and stable shell ridge or is a mobile shell ridge that becomes flattened from marine conditions and retreats to the interior of the marsh leaving a non-vegetated marsh edge exposed to erosional forces. The marsh edge platform, after the shell moves to the interior of the island, lacks above ground vegetation on the perimeter. Mendez et al (1999) found that to aboveground biomass works to dampen wave energy. Lacking aboveground biomass allows waves to wash farther onto the marsh platform and heavily vegetated marsh platforms with scarped terraces at the edges will break into blocks and be placed atop the marsh from wave activity (Mendez et al., 1999)

These models, in figures 21 and 22, suggest that if the process of mobile shell ridges, observed by Crawford (2018) and this research, continues then the marsh island will continue to lose total land area, as Ellison (2011) modeled for the St. Bernard marshes, and become shell islands and eventually subaqueous shell mounds.

4.3 Comparison to Previous Studies

Previous research was done on Little Bayou Pierre, next island to the southwest of Isle Au Pitre, by Crawford (2018). Little Bayou Pierre is approximately 3.6km from Isle Au Pitre (center of each island is where the measurements started/ended) at a 223.5-degree heading. This island has shell ridges present showing very similar characteristics to that of Isle Au Pitre. The study sites are relatively close in proximity thus experience approximately the same conditions.

Twelve loose shells were collected from the top of various shell ridges and were sent to be radiocarbon dated through *DirectAMS* by Crawford (2018). This was done to date the shells (modern age, ancient, or more in line with the St. Bernard delta complex/lobes) that then would aid in isolating the source of the shells (modern or relict) (Crawford, 2018). The *Crassostrea virginca* shells came back with uncalibrated ages of: 832 +/- 22, 269 +/- 26, 454 +/- 21, and 827 +/- 20, (Crawford, 2018). The *Rangia cuneata* came back with ages of: 2,125 +/- 28, 2,138 +/- 23, and 2,092 +/- 22 (Crawford, 2018). The underlined dates are the ones that correspond to the date of the St. Bernard Delta complex and they are all *Rangia* shells. This makes sense due to the very low salinity water habitat they prefer that was likely from the St. Bernard delta complex forming 1,000-2,500 ybp creating a more brackish environment rather than the saline environment this area is currently. This then suggests that the modern aged shells come from a man-made source like oyster fisheries or natural oyster reefs (Crawford, 2018).

Grab samples were done by Crawford (2018) offshore perpendicular to the island and there was little shell present in the grab samples. Of the 60 samples only 44 had 0-20% shell content, seven samples had 21-80% shell content, and only nine samples had 81-100% shell content (Crawford, 2018). The lack of shell in the grab samples points to the shells being excavated from local sedimentary horizons that go deeper than the grab sampler could reach (Crawford, 2018). It is thought that the shells are placed on the marsh platform during periodic storm episodes depending on the shell material offshore being available or not and the swell energy being large enough to move the shell onshore (Crawford, 2018). Due to COVID-19 halting field work and marine conditions considered unsafe so frequently grab samples were not completed off the shore of Isle Au Pitre. Crawford (2018) grab sample data is likely very similar off of Isle Au Pitre. It is a possibility that the present shell on Isle Au Pitre is being reworked along the shorelines, since the shells are broken down and a small amount are whole shells, and likely has no large source of new shell material being brought to the island.

Crawford (2018) monitored nine shell ridges where it was determined that five were stable and four were mobile. The mobile ridges were located along areas of the island that were more exposed to wave and fetch than the stable ridges (Crawford, 2018). The stable and mobile ridges did not give an evident pattern of more or less likelihood to fragment the marsh edge (Crawford, 2018). Isle Au Pitre has only mobile ridges and experienced similar behavior as what Crawford (2018) monitored.

Above and belowground biomass results from Crawford (2018) indicate that the aboveground biomass was impacted the most. Crawford observed that during a field visit a shell ridge was able to be dug up and it was noted that there was no vegetation present in the middle of the ridge at the dig site (Crawford, 2018). Crawford stated, "there was no vegetation present, indicating that while stable ridges move less and affect less vegetation behind it, it has clearly damaged the aboveground vegetation that was present underneath" (Crawford, 2018). The vegetation below shell ridges was of interest to me but was unable to be investigated due to the COVID-19 shut-downs and increased storm activity cutting into available days in the field. The aboveground biomass being impacted, whether the ridge was mobile or stable, is likely for Isle Au Pitre as Crawford (2018) confirmed for the ridges nearby at Little Bayou Pierre.

It is likely that the shell rimmed islands will erode completely, when sea level rise is considered as well, leaving behind subaqueous shell mounds. Ellison (2011) presented a conceptual geomorphic model that shows this progression in figure 22. Marsh islands with shell pocket beaches form by winnowing and shell deposition on the surface of the marsh. As the marsh fragments, more resistant landmasses are spared, and the pocket beaches become shell rimmed islands such as Isle Au Pitre. Eventually, relative level rise will become too prevalent, and the marsh will become submerged, and the shells accumulate in the shallow water above, forming mounds. As the pressures of relative sea level rise increase, the mound will become submerged and form a subaqueous shell mound (Ellison, 2011). This model from Ellison (2011) and the model from Crawford (2018) in figures 21 and 22 show the progression of Isle Au Pitre and the processes acting on it.

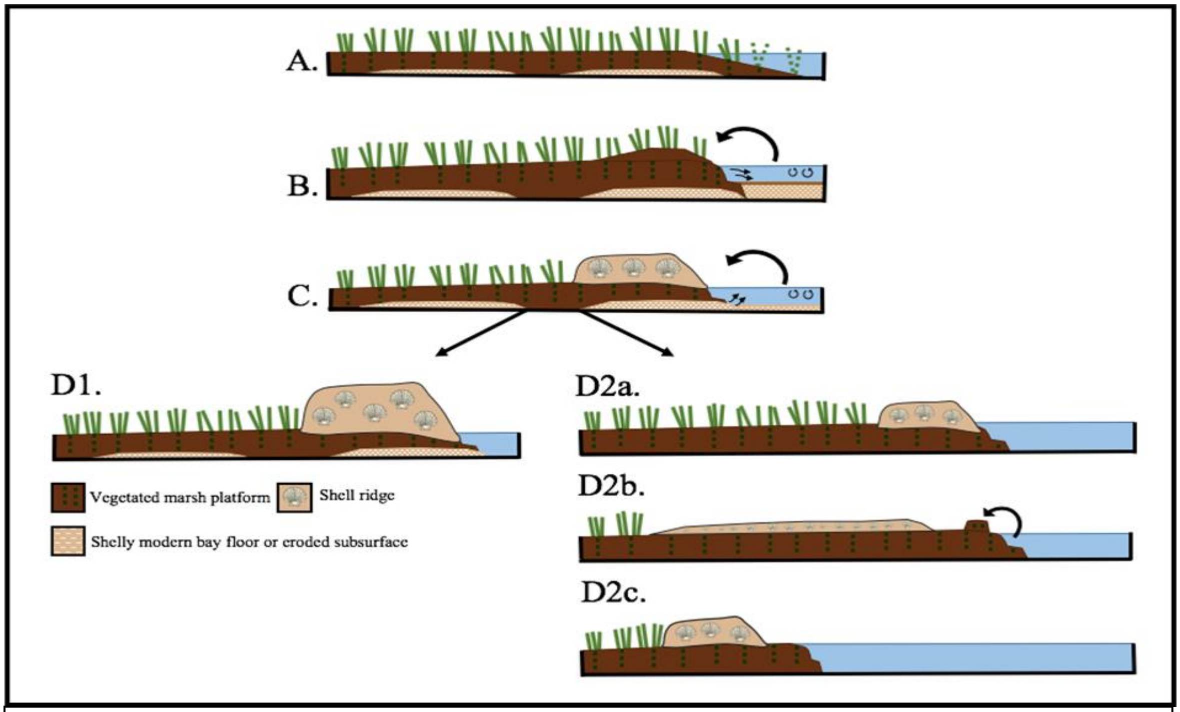


Figure 21: From Ellison (2011) and Wilson and Allison (2008) with modifications to the figure by Crawford (2018). D was previously a single phase but is now broken up into 4 separate phases as follows: D1, shell ridge is built up leading to it being stable with marsh vegetation behind. D2a and D2b, the shell ridge is shorter in vertical and lateral extent but soon after spreads out laterally across the marsh platform and subsequently exposes a section of marsh edge platform that lacks above ground vegetation but still has belowground biomass. Here, blocks of marsh edge can be transported onshore from wave action causing the marsh edge to retreat and the island to lose overall land area. D2c, the marsh edge platform now lacks above ground vegetation.

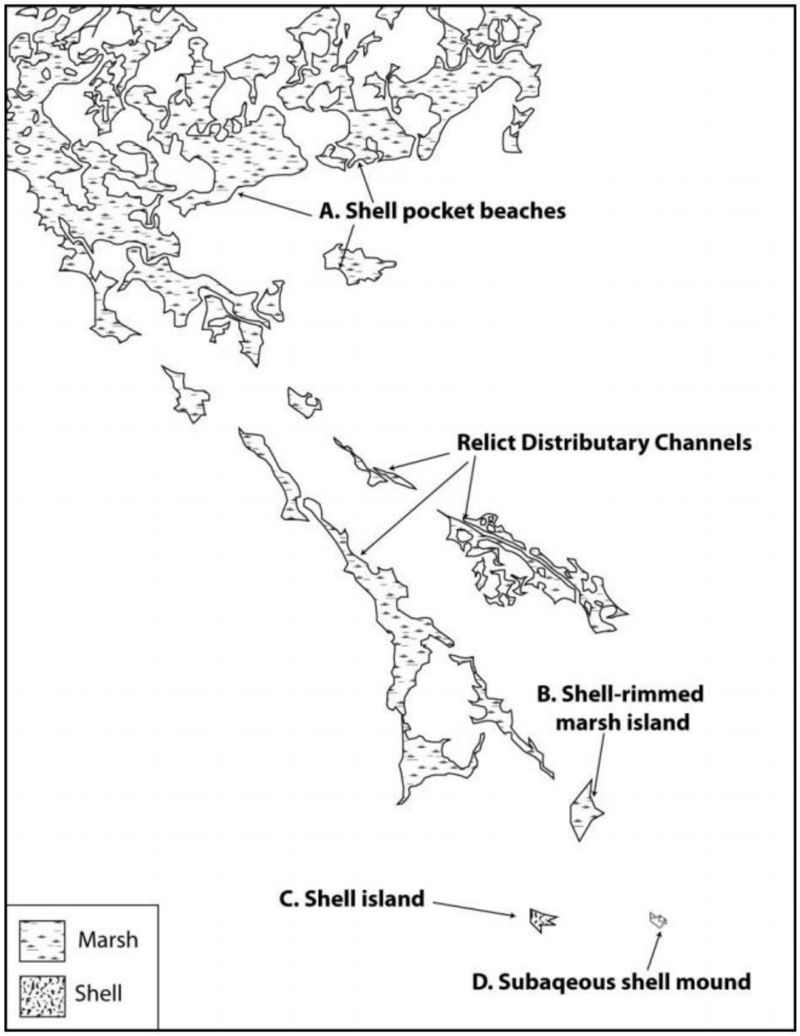


Figure 22: Plan-view conceptual geomorphic model from Ellison (2011). Model suggests a progression of shell pocket beaches to subaqueuos shell mounds. Relicit distributary channels are preferentially preserved due to their lithology being more resistant to erosion. As the channels become isolated, shell rimmed islands form and eventually become shell islands due to their inabilty to vertically accrete. Eventually, the entire mass submerges to a subaqueous shell mound.

4.4 Future Research Insights

Future research should focus on, aside from the shell ridges, is the impact of fluctuating water levels, interior ponding, and flooding. Tracking those changes during the course of numerous years will be very beneficial for a more complete understanding of Biloxi marsh evolution. Research done during a longer timeline of one to three years for two to three marsh islands instead of one island for one year would help to further resolve the evolution of this marsh.

Understanding what numerous storm seasons can impact on the movement and morphology of the shell ridges (active summer storms with small storms, low activity summer storms with only a few storms but of large size, or the average winter cold front season) and the marsh island itself, could open the door to restoration projects throughout Biloxi marsh.

4.5 Purpose

The overarching purpose of this research is not only to slow down marsh island erosion within Biloxi marsh for land, wildlife habitat, and fishing grounds, or. While that is important the shell ridges, marsh island, and land loss data can give provide an even greater purpose for understanding marsh evolution in the midst of relative sea level rise. This work and previous studies in the area with shell ridges can be applied in broader fields, such as marsh erosion and coastal protection in other areas of the world.

In coastal areas all over the world man-made shell reefs are placed offshore of areas that are experiencing erosion. The oyster reefs are placed where the erosion needs to be stopped or slowed. Coastal Louisiana has land restoration projects funded to slow or stop erosion, land loss, or build land as listed in the 2017 CMP. The research done on Isle Au Pitre has the chance to aid professionals in their own research and the results can benefit the development of marsh restoration projects. Currently, there are proposed habitat and shoreline restoration projects from the state and private companies to be done on Isle Au Pitre. This thesis research has the ability to aid in the planning and engineering of the projects to further the lifespan of the island for land area and nesting area for birds.

CHAPTER 5. CONCLUSION

Understanding all the processes at play that cause erosion in this region is crucial in understanding how marsh edge erosion can be minimized, how coast lines and coastal features can be restored for current and future generations, and how the landscape responds to different processes. Coastal Louisiana is, and has been, experiencing land loss and land building from an array of different processes. This research was a very small part of the bigger picture for coastal and southeast Louisiana.

The land loss rates within Louisiana's coastal marshes are the highest land loss rates in the United States due partly to relative sea-level rise (Barras et al., 2003). Land loss and marsh deterioration along the lower Mississippi river was documented as early as the 1930's by Russell (1936) but the deltaic plain is a 5,000 + year product of delta building (Gagliano et al., 1981). Louisiana has lost about 3,000km^2 of land from 1932-2010 with another 2,800km^2 at risk by 2060 (Couvillion et al., 2011).

Louisiana is not only at risk of losing land but also at risk of having an impacted economy due to land loss. Louisiana is at risk of losing $5.8 to $7.4 billion in annual output from the direct loss of land throughout coastal Louisiana (Barnes et al., 2017). Fisheries, tourism, and recreation in Louisiana are all economic activities that are offering provisions and cultural services and are all expected to be impacted by land loss or storm damage driven by land loss (Barnes et al., 2017). While this will most likely never be reversed, land loss rates of coastal Louisiana may be reduced by freshwater diversions and controlled sub delta growth (Gagliano et al., 1981).

This research shows that:

1. The total distribution and extent of shell ridges change in response to heightened storm activity and impact the island morphology and total land area. Throughout the research the shell line and shell ridges moved inland from the perimeter of the marsh. As the ridges move inland the edge of the marsh is left exposed with little to no above ground vegetation allowing waves to wash farther inland due to no vegetation being present to dampen wave energy (Méndez et al., 1999).
2. The shell ridges move and translate inland during and after storm activity. Due to the gap in data from March 12 to August 18 it cannot be concluded whether tropical cyclone season or cold front season had a greater or lesser impact than the other on ridge movement and/or erosion of the marsh platform.
3. The vegetation line retreats at progressively higher rates and the shore and shell line movement correlate with each other. The eastern side of the island experiences more shore, shell, and vegetation line retreat than the western side. The western side of the island, facing Mississippi, has fewer mobile ranges than the eastern side of the island, facing the open ocean. The more mobile ridges on the eastern side had a greater impact on the marsh than the less mobile ridges on the western side.

The Biloxi marsh is not projected to survive more than 30 more years (Day and Kemp, 2017). The projection was set by Kemp and Day, J (2017) in a comment report on the 2017 CMP for Louisiana and this research further supports the concern for the marsh survivability if it is not included in restoration projects. It is predicted that the marsh islands will inevitably erode but the pace at which they erode is not certain. This research approach may be used as a model for other marsh projects, or this marsh island, to better plan restoration projects and better understand land loss in coastal areas.

REFERENCES

Barbier, E.D., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., & Silliman, B.R. (2011). The Value of Estuarine and Coastal Systems. *Ecological Monographs, 81*(2). 169-193.

Barbier, E.D., Georgiou, I.Y., Enchelmeyer, B., & Reed, D.J. (2013). The Value of Wetlands in Protecting Southeast Louisiana from Hurricane Surges. *PLOS One, 8*(3).

Barnes, S. R., Bond, C., Burger, N., Anania, K., Strong, A., Weilant, S., & Virgets, S. (2017). Economic Evaluation of Coastal Land Loss in Louisiana. *Journal of Ocean and Coastal Economics*, *4* (1).

Barras, J., Beville, S., Britsch, D., Hartley, S., Hawes, S., Johnston, J., Kemp, P., Kinler, Q., Martucci, A., Porthouse, J., Reed, D., Roy, K., Sapkota, S., & Suhayda, J. (2003). Historical and projected coastal Louisiana land changes: 1978-2050. USGS. Open File Report 03-334, 39 p. (Revised January 2004).

Bluck, B.J. (1967) Sedimentation of Beach Gravels: Examples from South Wales. *Journal of Sedimentary Petrology, 37*. 128-156.

Coastal Protection and Restoration Authority of Louisiana. (2017). Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.

Coleman, J., Roberts, H., & Stone., G. (1998) Mississippi River Delta: An Overview. *Journal of Coastal Research, 14*(3). 698-716.

Couvillion, B., Steyer, G., Wang, H., Beck, H., & Rybczyk, J.M. (2013). Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios. *Journal of Coastal Research, 67*(sp1), 29-50.

Crawford, F. (2018). Classification and Geomorphology of Shell Berms: Effects on Marsh Stabilization in Biloxi Marshes, Louisiana. *University of New Orleans Theses and Dissertations.* 1-52.

Day Jr., J.W., Britsch, L.D., Hawes, S.R., Shaffer, G.P., Reed, D.J. & Cahoon, D. (2000). Pattern and process of land loss in the Mississippi Delta: a spatial and temporal analysis of wetland habitat change. *Estuaries*, *23*(4), 425-438.

Day, J., & Kemp, P. (2017). Restoration and Sustainability of the Biloxi Marsh Complex: Comments on the 2017 Comprehensive Master Plan: Comments: 2017 Louisiana Coastal Master Plan.

Day Jr., J.W. & Templet, P.H. (1989). Consequences of Sea Level Rise: Implications from the Mississippi Delta. *Coastal Management*, *17*(3), 241-257.

Duncan, J.R. (1964). The Effects of Water Table and Tide Cycle on Swash-Backwash Sediment Distribution and Beach Profile Development. *Marine Geology, 2*(3), 186-197.

Ellison, M. (2011) Subsurface Controls on Mainland Marsh Shoreline Response During Barrier Island Transgressive Submergence. *University of New Orleans Theses and Dissertations*. 1-133.

Flocks, J., Kulp, M., Smith, J., & Williams, S.J. (2009). Review of the Geologic History of the Pontchartrain Basin, Northern Gulf of Mexico*. Journal of Coastal Research*, *54*, 12-22.

Gagliano, S., Meyer-Arendt, K., & Wicker, K. (1981). Land Loss in the Mississippi River Deltaic Plain. *Gulf Coast Association of Geologic Societies, 31*, 295-300.

Gramling, R., &Hagelman, R. (2005). A Working Coast: People in the Louisiana Wetlands. *Journal of Coastal Research, 10* (272), 112-133.

Guo, B., Subrahmanyam, M.V., & Li, C. (2020). Waves on Louisiana Continental Shelf Influenced by Atmospheric Fronts. *Scientific Reports*, 10, 272

Jevrejeva, S., Moore, J.C., Grinsted, A., & Woodworth, P.L. (2008). Recent Global Sea Level Acceleration Started Over 200 Years Ago? *Geophysical Research Letters, 35*(8).

Kemp, G. P., & J. W. Day. (2017). Restoration and Sustainability of the Biloxi Marsh Complex: Comments on the 2017 Comprehensive Master Plan. Prepared for the Biloxi Marsh Corporation.

Kulp, M., Penland, S., Williams, S.J., Jenkins, C., Flocks, J., & Kindinger, J. (2005). Geologic Framework, Evolution, and Sediment Resources for Restoration of the Louisiana Coastal Zone*. Journal of Coastal Research, SI* (44), 56-71.

Mariotti, G., Fagherazzi, S., Wiberg, P.L., McGlathery, K.J., Carniello, L. & Defina, A. (2010). Influence of Storm Surges and Sea Level on Shallow Tidal Basin Erosive Processes. *Journal of Geophysical Research*, *115.*

Medeiros, L. (2020, September 08). *U.S States with the Longest Coastlines*. World Atlas. https://www.worldatlas.com/articles/us-states-by-length-of-coastline.html

Medellín, G., &Torres- Freyermuth, A. (2019). Morphodynamics Along a Micro-Tidal Sea Breeze Dominated Beach in the Vicinity of Coastal Structures. *Marine Geology*, *417*.

Méndez, F.J., Losada, I.J., Losada, M. (1999). Hydrodynamics Induced by Wind Waves in a Vegetation Field. *Journal of Geophysical Research, 104*(C8). 18,383-18,396.

Moeller, C., Huh, O.K., Roberts, H., Gumley, L., & Menzel, W.P. (1993). Response of Louisiana Coastal Environments to a Cold Front Passage. *Journal of Coastal Research*, 9(2), 434–447.

Narayan, S., Beck, M.W., Wilson, P., *et al.* (2017). The Value of Coastal Wetlands for Flood Damage Reduction in the Northeastern USA. *Scientific Reports,* 7(9463).

National Hurricane Center. (2021). *Glossary of NHC Terms*. https://www.nhc.noaa.gov/aboutgloss.shtml

Orford, J., Forbes, D,. & Jennings, S. (2002). Organizational Controls, Typologies, and Time Scales of Paraglacial Gravel-Dominated Coastal Systems, *Geomorphology*, *48*, 51-85.

Reed D.J. (2009). Planning for the Future of the Pontchartrain Coast. *Journal of Coastal Research*, *SI*(54), 198-205.

Roberts, H.H. (1997) Dynamic Changes of the Holocene Mississippi River Delta Plain: The Delta Cycle. *Journal of Coastal Research, 13*(3). 605-6272.

Sun, F., & Carson, R. (2020). Coastal Wetlands Reduce Property Damage During Tropical Cyclones. *Proceedings of the National Academy of Sciences, 117*(11), 5719-5725.

Törnqvist, T., Bick, S., Borg, K., & Jong, A.F.M. (2006) How Stable is the Mississippi Delta? *Geology, 34*(8). 697-700.

Thomason, R., (2016). Biloxi Marsh Platform Response due to Meteorological Forcing. *University of New Orleans Theses and Dissertations*. 1-103.

University of Illinois at Urbana-Champaign's Department of Atmospheric Sciences – Weather World 2010 Project. *Precipitation Along a Cold Front,* viewed 01 February 2021, <http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/af/frnts/cfrnt/prcp.rxml>.

Wamsley, T.V., Cialone, M.A., Smith, J.M., Atkinson, J.H., & Rosati, J.D. (2010). The Potential of Wetlands in Reducing Storm Surge. *Ocean Engineering, 37*. 56-68.

Wentworth, C.K. (1922). A Scale of Grade and Class Terms for Clastic Sediments." *The Journal of Geology, 30*(5). 377–392.

Wilson, C.A. & Allison, M.A. (2008). An Equilibrium Profile Model for Retreating Marsh Shorelines in Southeast Louisiana. *Estuarine, Coastal and Shelf Science*, *80*(4). 483-494.

Vita

The author was born and raised in a small town on the southern portion of the Puget Sound in Washington State. She obtained her undergraduate degree from Central Washington University in Environmental Science with a specialization in Geology in June of 2018 located in Ellensburg, Washington. Shortly after graduating she packed up her animals and moved to Dauphin Island, Alabama where she worked for Auburn University's shellfish lab for the summer. She started her master's program at the University of New Orleans in August of 2018 focusing on coastal studies and geomorphology. Her next step in life is moving back to the PNW with her husband and cats to build a home and start a family.