ECOLOGICAL RESPONSES TO A RECENTLY CONSTRUCTED BREAKWATER JETTY IN LAKE PONTCHARTRAIN, LOUISIANA

By
Gary P. Shaffer
Tyler A. Stevens
Christopher Beachy

Final Report

Southeastern Louisiana University
Hammond, Louisiana

February 28, 2019

Abstract

To protect and restore Louisiana's rapidly degrading wetlands, a variety of restoration and conservation projects have been implemented throughout the state. These projects include many strategies for combatting the factors contributing to wetland loss, one of which is the construction of breakwater jetties along shorelines highly impacted by wave erosion. The purpose of this study was to examine several aspects of the ecosystem surrounding a breakwater jetty constructed near the Tangipahoa River in Lake Pontchartrain, Louisiana.

Vegetation, hydrologic and terrain changes since completion of construction was determined by analyzing a combination of historic imagery and drone imagery with ArcGIS mapping procedures. The fish community was surveyed at sample points along the jetty and nearby natural shoreline to provide information on the status of the marine ecosystem surrounding the jetty. Baldcypress (*Taxodium distichum*) saplings have been planted along the jetty to determine the suitability of the area for baldcypress growth and the potential for sustainable swamp formation. In addition, we are currently deploying 800 Christmas trees to the western end of the jetty in attempt to enhance sediment accretion. Hopefully, the data collected from this study provide information that will assist in the planning of the next phases of jetty construction for this site, as well as influence construction planning for similar shoreline protection projects in the future.

Key words: jetty, coastal wetlands, shoreline loss, land building, wave erosion, restoration, Louisiana

TABLE OF CONTENTS

INTRODUCTION

The wetlands of the Lower Mississippi River Delta are considered one of the most significant ecosystems in the world, consisting of approximately 5,800 mi^2 wetlands (Couvillion et al., 2011). This vast expanse of wetlands is supported by the Mississippi River Drainage Basin, which acts as a watershed for approximately 41% of the contiguous United States (Turner & Rabalais, 1991) . This watershed acts as a drainage basin for 31 states and covers an area of approximately 1,245,000 mi^2, making it the third largest drainage basin in the world (Couvillion et al., 2011; Turner & Rabalais, 1991). Over a period of approximately 7,500 years, the water, sediments and nutrients carried by the Mississippi River Drainage Basin created the Lower Mississippi River Delta and has allowed for the formation of large areas of coastal wetlands (Britsch et al., 1993; Reed & Wilson, 2004). The coastal wetlands of Louisiana account for approximately 37% of all the coastal wetlands of the United States (Couvillion et al., 2011) .

These wetlands serve a variety of functions that are vital to the Louisiana and global economy including navigation ports for cargo, an estimated 500-million tons worth per year, and avenues of gas and oil exploration (CPRA, 2017). The wetland ecosystem buffers storm damage, with baldcypress and water tupelo (*Taxodium distichum – Nyssa aquatica*) swamps possessing the ability to significantly reduce the impact of storm surge, the damaging waves atop the surge and wind damage (Shaffer et al., 2009a). Ecologically, these wetlands support a large diversity of life, providing habitat for approximately 3.28-million migratory birds and other wildlife including mammals, reptiles, and a diverse fish and shellfish population (CPRA, 2017). This biodiversity also generates a substantial amount of revenue for the state of Louisiana, which includes the second largest fishery in the country (CPRA, 2017). Due to the combination of all of these factors, the overall value of the ecological systems of the Lower Mississippi River Delta have been estimated at $4.7 trillion (Batker et al., 2010).

Unfortunately, this ecosystem is rapidly degrading. Coastal wetland loss of Louisiana represents 90% of the total wetland loss of the United States (Couvillion et al., 2011). Between 1932-2010, coastal Louisiana lost approximately 1,883 mi^2 of land (Couvillion et al., 2011). The yearly land loss rate of 16.57 mi^2 between 1985 and 2010 equates to losing an area the size of a football field every hour (Couvillion et al., 2011). If these land loss rates continue, an additional 965 mi^2 will be lost by 2050 (Cowan et al., 2014). There are many factors that contribute to wetland loss including the construction of the levee system, canal dredging, oil and gas exploration, subsidence, eustatic sea level rise, invasive species and wave erosion (Day et al., 2000). The wetland loss of Louisiana is the result of these factors along with others and the complex interactions and relationships among them (Reed & Wilson, 2004). Due to this wetland loss and degradation, the terrain and vegetative composition of the wetlands of Louisiana has been dramatically altered from its natural state. Coastal marshes are being converted into open water, and areas historically dominated by baldcypress and water tupelo are being converted into marsh, shrub scrub and open water (Shaffer et al., 2009b, 2016).

The degradation and loss of these wetlands produces effects that impact the wildlife dependent upon them. Approximately 75% of the fish and shellfish species of Louisiana's commercial fisheries depend on these wetlands for spawning, feeding and nursery habitat (CPRA, 2017). The nutrients derived from the wetlands are carried into the shallow continental shelf south of Louisiana in the Gulf of Mexico, and the use of these nutrients may occur outside the boundaries of the wetlands (Cowan et al., 2014; Mitsch and Gosselink, 2015). Therefore, the effects of wetland loss have the potential to extend well beyond the physical boundaries of the wetlands. It has been shown that habitat destruction, especially wetland loss, is responsible for up to half of the nation's decrease in fishery stocks (Chesney et al., 2010). However, Louisiana has not shown any reduction or changes in fishery landings despite suffering the highest amount of wetland loss in the country (Chesney et al., 2000). There are several factors that could be allowing for this resiliency to habitat destruction, but a productive fishery can still be on the verge of collapse (Chesney et al., 2000). Some of the explanations for the stability of the fisheries of Louisiana include an increase in the abundance of macrophytes in the newly established shallow open water habitats, turbidity of Louisiana's waters providing an alternative form of refuge, and the use of the increased amount of marsh edge habitat resulting from marsh fragmentation (Chesney et al., 2000; Cowan et al., 2014; Jerabek, et al., 2017). Therefore, despite currently displaying no decrease in fisheries production, the degradation of Louisiana's wetlands could have an enormous impact on fisheries in the near future. Continued efforts to examine how fish and marine communities are potentially affected by wetland loss and the restoration projects designed to protect and restore wetlands are necessary to create the most efficient strategies for combatting wetland loss. Studies focusing on fish communities have potential to reveal significant information considering how fish serve as a bioindicator of a local ecosystem due to their ability to rapidly colonize suitable habitat or immigrate from an area of disturbance or degraded habitat (Thom et al., 2004).

Due to the complexity of wetland loss, many strategies are required for restoration and protection of the degrading wetlands of Louisiana. As of 2011, the Coastal Protection and Restoration Authority (CPRA) reported a total of 184 completed projects with another 208 projects in progress (CPRA, 2011). These projects include restoration plantings, river diversions, barrier island restorations, marsh creation projects, levee gapping, and shoreline protection projects (CPRA, 2011; 2017).

Breakwater jetties are a type of shoreline protection, aligned parallel to the shoreline that serve as a barrier to dissipate wave energy and prevent erosion in areas highly impacted by waves (Barnard, 1993). Wave erosion is a major cause of coastal wetland loss in Louisiana, accounting for approximately 26% of the total land loss (Penland et al., 2001). By reducing the force generated by waves, the area between the shoreline and the breakwater becomes a relatively low energy zone allowing for sediment to settle out of the water column and form sediment deposits (Barnard, 1993). This deposited sediment creates an environment suitable for vegetative succession and colonization by the local fauna (Barnard, 1993). While successfully protecting the coastline from wave erosion and promoting sediment accretion, these breakwater jetties also create an unnatural, sheltered habitat that can promote the establishment of communities that differ in species richness and diversity from the naturally occurring, surrounding shoreline (Bulleri & Chapman, 2010; Guidetti et al., 2005; Vaselli et al., 2008).

“Fish dips” are openings incorporated into the breakwater jetty construction plan that are designed to mitigate this issue by facilitating the passage of marine life, creating a more natural ecosystem and maintaining water quality behind the jetty (Chen et al., 2016). However, breakwater jetties with fish dips are less efficient at preventing the effects of wave erosion than non-segmented, continuous jetties (Chen et al., 2016). Unbroken waves travelling through the fish dips can result in erosion of the shoreline directly behind and adjacent to the fish dip (Chen et al., 2016). During storm events when the breakwater is completely submerged, wave amplifications and rip currents can be produced resulting in significant sediment outflow through the fish dips (Chen et al., 2016). The width of the fish dip determines the water residence time behind the breakwater, so an opening too small or too large could affect water quality (Chen et al., 2016). Therefore, the ratio of fish dips to continuous jetty and fish dip width are critical factors in the project design of jetties (Chen et al., 2016). The National Oceanic and Atmospheric Administration (NOAA) recommends that fish dips be at least 20 feet wide every 1000 linear feet of jetty, but no optimal design guideline currently exists for the layout of fish dips (Chen et al., 2016). The use of modeling has supplied a significant amount of research in regards to the effects of fish dips and breakwaters on sediment accretion. However, the necessity of fish dips in regard to the establishment of a healthy, natural ecosystem surrounding jetty project site remains relatively unexplored.

The purpose of this study is to examine the effects of a recently constructed breakwater jetty on the surrounding ecosystem with regard to terrain and vegetation changes, fish communities, and potential for baldcypress growth and sustainability. The terrain and vegetation were mapped using ArcGIS to determine changes in the area surrounding the jetty since construction. Fish communities were sampled along the natural shoreline and various points on the leeward side of the jetty to compare fish populations occurring on the natural shoreline with fish populations surrounding the interior of the jetty. Baldcypress saplings were planted in recently created sediment deposits along the jetty to examine baldcypress growth and survival and the potential for sustainable swamp formation. Hopefully, the results of this study will provide information on the status of the local ecosystem and will assist in the planning of the next phases of the jetty construction for this site, as well as influence construction planning for similar projects in the future.

METHODOLOGY

Study Site

The Lake Pontchartrain Basin is approximately 1,600 mi^2 in southeastern Louisiana, comprised of the 630 mi^2 of Lake Pontchartrain, 93 mi^2 of Lake Maurepas and the surrounding wetlands (Saucier, 1968). The wetlands of the Basin, historically 90% baldcypress and water tupelo swamp, have been dramatically degraded by a variety of wetland loss factors such as the extensive baldcypress logging of the late 19th and early 20th century, lack of nutrients, saltwater intrusion and wave erosion along exposed shoreline (Day et al., 2000; Saucier, 1968; Shaffer et al., 2009b; 2015; 2016). The 3.5-mile span of shoreline of Lake Pontchartrain between Pass Manchac and the Tangipahoa

River has been severely impacted by wave erosion, with land loss rates historically averaging between 5–19 ft/yr and averaging 9.8 ft/yr (HDR, 2011; USGS, 2002).

In response to this significant land loss, the Lake Pontchartrain Shoreline Protection Project, a breakwater jetty, was proposed in 2012 and construction began on the first phase in 2013 (HDR, 2011). This is the first of three phases projected to total approximately 3.2 miles in length. The first phase of construction was approximately 9,200 feet of rock jetty constructed 300 feet offshore. Fish dips varying from 8–30 feet in width were constructed every 1000 feet. The project began near the mouth of the Tangipahoa River and construction progressed west along the shoreline towards Pass Manchac.

Between November of 2017 and March of 2018, the US Army Corps of Engineers performed a dredging project at the mouth of the Tangipahoa River. Typically, these dredging projects pump the dredged sediment offshore. However, the eastern end of the breakwater jetty ends approximately 1,500 feet from the mouth of the River so it was decided that the sediment would instead be pumped to the leeward side of the jetty. Approximately 100,000 cubic yards of dredged sediment and shell was pumped behind the jetty, rapidly altering the terrain and hydrology of the area between the shoreline and jetty.

The eastern opening of the jetty was completely enclosed due to this large influx of sediment, and a large mudflat was formed in the center of what was once a free flowing canal. The two eastern-most fish dips also were closed or made very shallow.

This created an isolated environment with increased elevation and little inflow of fresh water to the leeward side of the jetty.

The western end of the jetty has not been as dramatically affected by the dredging project or by natural sediment accretion. This remains mostly open water with some herbaceous marsh. One of the fish dips of the western end of the jetty has been closed off due to sediment accretion and vegetation establishment, but all other fish dips are open, allowing for the free flowing movement of water and aquatic fauna.

Vegetation and Terrain Survey

Changes in vegetation and terrain of the area surrounding the jetty were analyzed using ArcGIS 10.2.2. Two satellite images from Google Earth were collected from May of 2017 and January of 2018. Images imported from Google Earth into ArcGIS do not contain geographic information, so each image was geo-referenced using a base map provided in the ArcGIS software. The geo-referencing process involves selecting points from the imported images and referencing them with specific points on the base map that contains all necessary geographic information. A total of ten geo-referencing points distributed throughout the images were selected to provide an accurate geo-reference.

In combination with the satellite images, drone imagery was incorporated into the study as well. The drone flight, performed by ELOS Environmental, took place on October 19, 2018. This image provides the most recent information regarding the current status of vegetative succession in the area and the terrain changes associated with natural sediment accretion and the accretion resulting from the dredging project performed in 2017.

These images were processed in ArcGIS using a combination of an Unsupervised Remote Sensing Classification and manual creation of features to classify the images into four categories: woody vegetation, herbaceous vegetation, mudflat and open water. This classification process incorporates an iso-cluster, maximum-likelihood algorithm to define individual pixels and groups of pixels within the images into specific categories. Once the classification was complete, this map was used as a guide, along with the most recent drone image, for manual creation of features onto a new shapefile. Ground-truthing, a process in which the geographic categories and values created by ArcGIS are verified by field confirmation, was performed at the project site and all categories were 100% accurate.

Once the classification was complete and the accuracy of the classification had been verified, the acreage of each category of terrain and vegetation was calculated for the area surrounding the jetty. These values were obtained by calculating the number of pixels within in each category and comparing these values with the total number of pixels contained within the jetty. The percent coverage and acreage of each category contained in the maps was compared to determine the changes in vegetation and terrain surrounding the jetty over time and the mechanisms responsible for the changes.

Fish Survey

The fish population was surveyed by seining along transects of each habitat type. Sampling was performed along box-shaped transects perpendicular to the shoreline with a 10-foot seine. The seining process began at the shoreline and ended when it extended to the opposite jetty or mudflat, or when the water depth reached approximately

4 feet. At depths deeper than 4 feet, seining was not possible. Fish were placed on ice in individually labeled bags for each sample site and preserved. The fish were fixed with 10% formalin for a period of seven days, placed in water for seven days and then placed in 70% ethyl alcohol solution for preservation. Following identification of each specimen, catch totals and species richness were determined for each sample point. Salinity, dissolved oxygen content and temperature were measured at the center of each habitat type with a YSI water quality meter. Water depth was measured along transects with a survey rod every 100 feet for areas of open water and this sampling distance was adjusted for the width of more narrow areas to obtain the goal of three evenly distributed measurements of depth for each transect. This survey will be replicated over four seasons. Species diversity was calculated using Shannon's Diversity Index. ANOVA and Multisource Regression analysis will be performed in SYSTAT to determine relationships among measured variables and the catch totals and species diversity of the fish community at each transect and habitat type.

To properly survey the fish community surrounding the jetty, twelve total sample sites were divided into four distinct habitat types; natural shoreline (Natural), protected shoreline with high water flow (Protected-High), protected shoreline with partially restricted inflow of water (Protected-Intermediate), and
protected shoreline with completely restricted inflow of water (Protected-Restricted).

The three replicates for the Natural habitat were 1000 feet apart and begin 1000 feet from the western end of the breakwater jetty. This site consists of open water, cypress stumps and herbaceous marsh. Due to the lack of protection from the jetty, this area is exposed and highly impacted by wind and waves.

The sample sites for the Protected-High habitat begin at the western end of the jetty where water flows freely from the opening of the jetty and the first fish dip. The sample sites are 500 feet apart with the middle transect being centered on the first fish dip. Due to the protection provided by the jetty, this area is subject to less wave effects than the Natural site, but still receives some wind and wave effects with high water flow due to its location at the open end of the jetty.

The sample sites for the Protected-Intermediate habitat are located approximately 2,500 ft from the western end of the jetty. These sites are centered on a fish dip that has been closed off due to sediment accretion and vegetative establishment resulting in a habitat completely protected from the effects of wind and waves. This also prevents water flow directly to the center of the sample site, with only partial inflow of water from the surrounding fish dips and open end of the western jetty.

The sample sites for the Protected-Restricted habitat are at the eastern end of the jetty where sediment from the dredging project has completely closed off the opening of the jetty and the nearest fish dip. The sample sites are approximately 6,500 feet from the western end of the jetty. Inflow of water is almost completely prevented in this area, and the majority of the water that exists in this habitat is backflow from the western end of the jetty.

Baldcypress Sapling Planting

A total of 100 baldcypress saplings have been tagged, planted and protected from nutria herbivory at the project site. Initial diameter values were taken for each tree with a digital caliper. Fifty of the saplings were planted on a mud flat on the eastern end of the jetty along three transects running parallel to the jetty. The remaining fifty baldcypress saplings were planted on the western end of the jetty along three transects parallel to the jetty. Diameter growth and mortality rates will be monitored following one full growing season during fall, 2019. Multisource Regression and ANOVA will be performed to determine the relationships among several variables and the differences between sampling sites.

To obtain interstitial soil salinity values, salinity wells were placed in the center of the transects at each end of the jetty. These wells were constructed using 4-foot sections of 2-inch PVC pipe. Slits ¼ inch wide were cut into opposite sides of the lower portion of the pipe approximately 2 inches apart. These slits allow for the water in the soil to enter the pipe while preventing the pipe from being filled with sediment. The pipes were capped at both ends and the pipe was inserted vertically into the soil. The end with the slits was inserted to a depth of 1 foot below the sediment so that the top slit was just below the sediment surface. Salinity measurements will be taken monthly for the duration of the experiment to determine if soil salinity differed between the two sites. A 2-sample t test will be performed to determine if there are significant differences in salinity between the two sample sites.

Soil core samples were collected at various points along the planting transects to determine soil strength of the two sites. Samples were collected using a power drill coring device with a diameter of 3.6 cm and height of 10 cm, resulting in a volume within the corer of 101.788 cm^3. These samples were placed individually in a 150 °F drying oven for a period of 2 weeks to ensure complete drying. The samples were then weighed and bulk density was calculated by dividing the weight of the sample by the volume of the coring device. After bulk density values were obtained, the samples were then placed in a kiln at 500 °F for a period of 24 hours to eliminate all organic material. Once removed from the kiln, these samples were weighed again. The difference in weight from prior to being placed in the kiln to completion of the kiln burning process represents the weight of organic material contained in the soil. This value allows for the percent organic material of the soil to be calculated. A total of four samples were taken at the western and eastern end of the jetty to get a true representation of the soil strength of each of the planting sites. A second set of samples will be taken at the conclusion of the experiment. Two-sample t tests will be performed to determine differences in bulk density and percent organic content in the sample sites.

RESULTS & DISCUSSION

Vegetation and Terrain Survey

Analysis performed in ArcGIS indicates a net land gain of 23.8 acres occurred from May of 2017 to October of 2018 (Figure 1). An additional 18.3 acres of herbaceous vegetation and 17.3 acres of woody vegetation coverage of mudflat occurred during this time frame (Figure 1). This significant increase in land gain and vegetation coverage is attributable to conversion of both previously existing mudflat and the approximately 51 acres of sediment deposited to the eastern portion of the jetty during the dredging project. The large mudflat created by the dredging project was almost entirely converted to woody and herbaceous vegetation by October of 2018. The introduction of the large amount of sediment from the dredging project produced dramatic terrain changes that would have taken much longer to naturally occur. The eastern end of the jetty now resembles a swamp habitat with large portions of previously vacant mudflat being heavily populated with black willow (*Salix nigra*). Naturally occurring baldcypress saplings have also been found on the mudflats on the eastern end of the jetty. In all, 71.2 acres of land have been built since 2013.

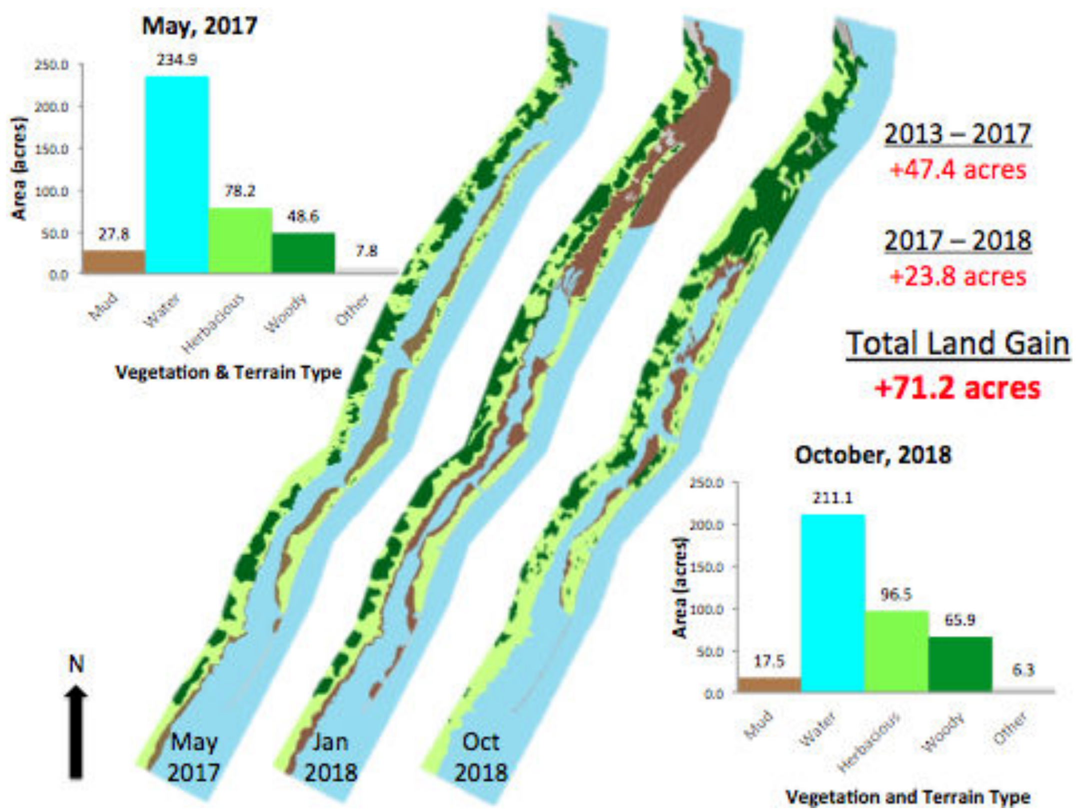
Fish Survey

Figure 1. Vegetation and Terrain Variation: May 2017 - October 2018.

While the construction of the jetty and the rapid addition of sediment and land gain may be considered beneficial for sediment accretion and vegetative establishment, the impact on fisheries will likely be more complicated due to the complexity of fish communities and their interactions with the local ecosystem. Evidence has shown assemblages of fish and various other biota surrounding

shoreline defense structures can be significantly different from the natural, unprotected shoreline (Bulleri & Chapman, 2010; Glasby & Connell, 1999). Catch totals are expected to decrease and species richness is likely to be significantly

different as the sample sites progress from open shoreline at the western end of the jetty to areas of heavily restricted water flow near the eastern end of the jetty. Decrease in



water depth and dissolved oxygen and an increase in temperature are likely to occur in the eastern areas of the jetty due to the restriction of water flow and proximity to the dredging site, which will likely have an impact on the fish communities present in those areas. Initial seining results for the fall season indicate a substantial decrease in fish abundance as the habitat types progress from natural shoreline towards the protected and restricted waters of the breakwater (Table 1, Figure 2). Also, a possible relationship between species diversity and habitat type may exist. Early data from one sampling season indicates an increase in species diversity as the habitats progress from natural shoreline to the restricted site, with a peak in species diversity at the Protected-Restricted habitat (Table 1, Figure 2). Additional data from each season will be required to confirm any potential significant relationships that may exist among the habitat types and other variables measured in this study.

Baldcypress Sapling Planting

Salinity, light availability, nutrient availability, soil composition, water regime, vegetative competition and a variety of other factors contribute to the growth and survival of baldcypress (Shaffer et al., 2009b; 2016). Therefore, hypothesizing the outcome of planting experiments can be difficult. However, the two planting sites along the jetty, while similar in some aspects and located along the same shoreline, may possess some differences in abiotic and biotic characteristics that may produce significantly different results. If the results from this study determine either one of these planting sites to be suitable habitat for baldcypress growth and sustainability, this could become a potential site for future, large-scale baldcypress plantings.

Baldcypress are considered a salt-sensitive species with a salinity survival threshold of approximately 6-8 ppt, but periods of even slightly elevated salinity can have an effect on mortality rates and growth (Allen et al., 1996; Conner & Inabinette, 2005; Krauss et al., 2000; 2017). Initial measurements indicate a potential

difference in salinity between the eastern and western planting sites. Without additional data it is not yet possible to determine if this difference is statistically

Table 1. *Fall 2018 fish catch totals from seining four habitat types of breakwater jetty*

Fish Species	N[1]	P-H[2]	P-I[3]	P-R[4]

Anchoa mitchilli – Bay Anchovi	2615	1261	545	43
Menidia beryllina – Inland Silverside	5	6	17	77
Strongylura marina – Atlantic Needlefish	1	-	-	-
Trinectes maculatus – Hogchoker	-	-	6	-
Poecilia latipinna – Sailfin Molly	-	-	-	6
Heterandria formosa – Least Killifish	-	-	1	2
Gambusia affinis – Mosquitofish	1	-	-	25
Sygnathus spp. – Pipefish	-	-	2	2

[1] N = natural shoreline

[2] P-H = protected shoreline with high water flow

[3] P-I = protected shoreline with intermediate water flow

[4] P-R = protected shoreline with restricted water flow

significant, but it appears the eastern site may have a slightly higher interstitial salinity. While this difference may be minimal, salinity has been determined as one of the most important factors for swamp tree production (Shaffer et al., 2009b; 2016). Therefore, a marginal difference in salinity concentration between the sites could result in significant differences in mortality and growth of the baldcypress saplings.

The saplings planted at the eastern site were planted on a mudflat in a swamp-like environment created by the USACE dredging project, while the trees planted at the western site are planted in open water and marsh environment. The bulk densities of the initial core samples collected from these two sites were

significantly different ($F_{1,7}$=36.511, p=0.001) (Figure 3). The bulk density of the

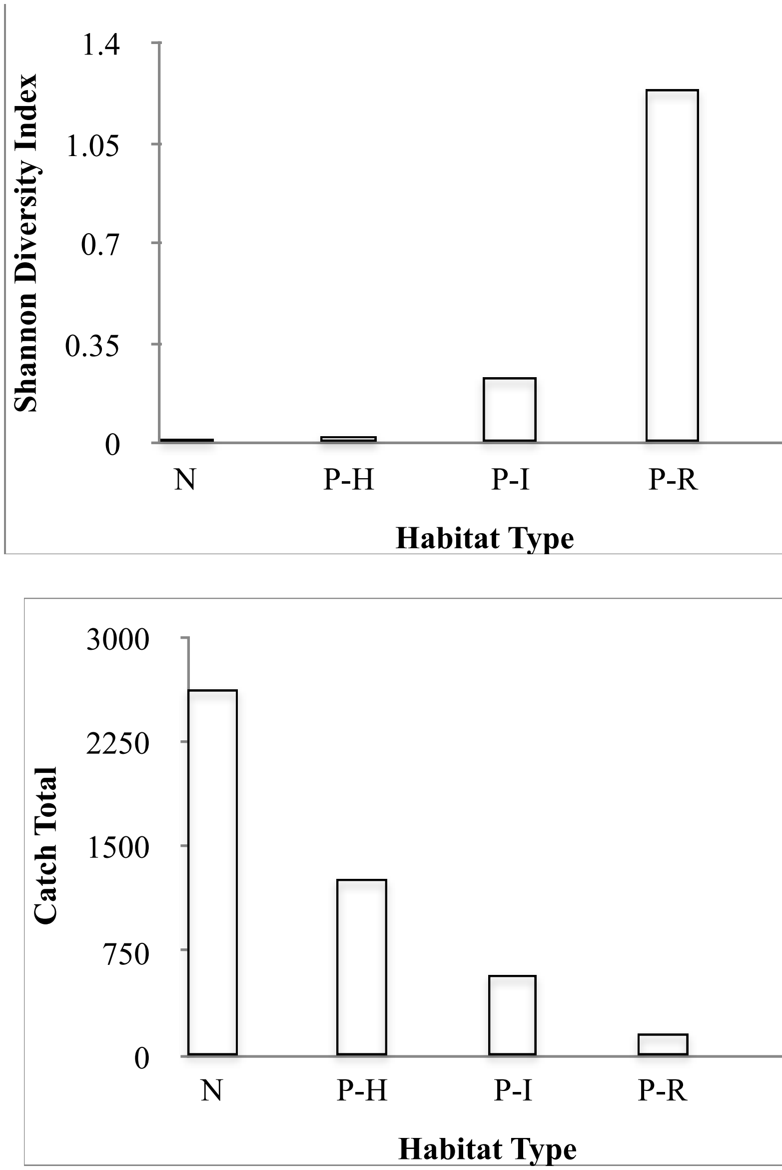


Figure 2. Fall 2018 Fish Catch Totals and Diversity for Four Habitat Types.

eastern site (mean=1.511 g cm^{-3} ± 0.072 g cm^{-3} (s.e)) was higher than the bulk density of the western site (mean=0.900 g cm^{-3} ± 0.071 g cm^{-3}). The higher bulk density of the eastern site is likely due to the large sediment deposits and shell contained in the soil resulting from the dredging project. Evidence from previous

studies has shown that bulk density is a major contributor to growth of woody tree

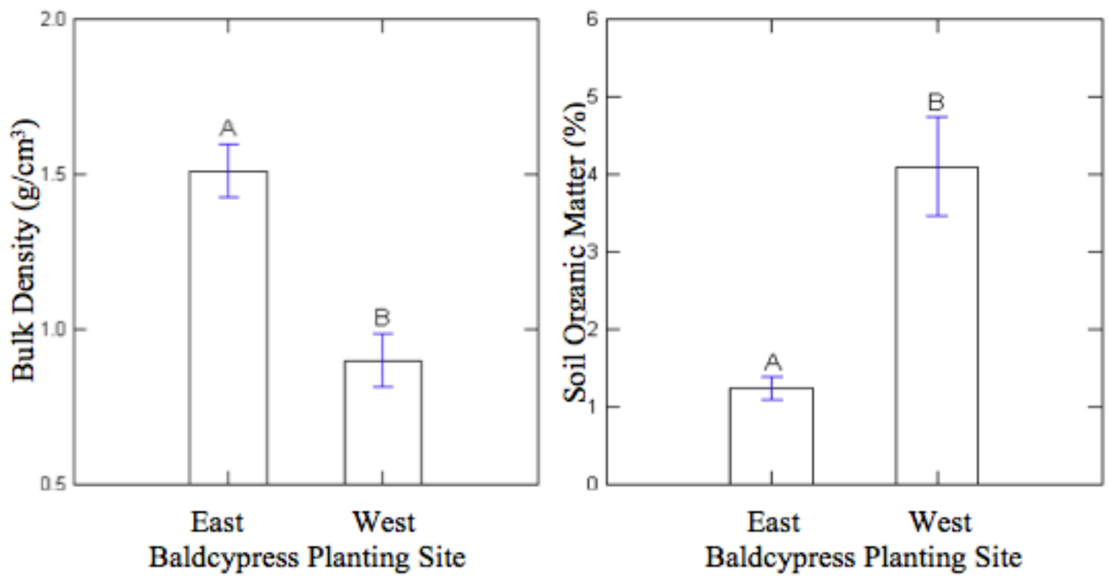


Figure 3. Bulk Density and Soil Organic Matter of Baldcypress Planting Sites.

species, so this may produce significantly different results with regard to the growth and survival among the two sites (Shaffer et al., 2003; Shaffer et al., 2009b). The soil organic content of the initial core samples collected from these two sites was also significantly different ($F_{1,7}$=27.383, p=0.002) (Figure 3). The percent organic content of the eastern site (mean=1.242 % ± 0.123 (s.e.)) was lower than the percent organic content of the western site (mean=4.100 % ± 0.532). In both cases soil strength was an order of magnitude higher than that of the Manchac/Maurepas swamp (Shaffer et al., 2016).

Vegetative competition for sunlight also may be a factor in the growth and survival of the baldcypress saplings between the two planting sites. The saplings for the eastern site were planted along transects in an area dominated by black willow (*Salix nigra*) saplings as tall as 8 feet, so sunlight will likely be less available at this site. Clearing and routine maintenance on both sites will be performed periodically, but this may not completely eliminate the issue. The saplings planted along the western end of the jetty were planted among patches of chickenspike (*Sphenoclea zeylanica*), which is dormant in the winter and does not grow tall enough to prevent sufficient light from reaching the baldcypress saplings. This difference in vegetative competition, while partially controlled, could result in differences in the growth of the planted saplings.

In response to the wetland loss of Louisiana, hundreds of federally and state funded restoration and protection projects have already been completed, with hundreds more currently in progress and proposed for the future. The CPRA "Louisiana's Comprehensive Master Plan for a Sustainable Coast" was released in June of 2017, consisting of a master plan to invest $50 billion over the next 50 years in 124 projects that build or maintain over 800 mi^2 of land (CPRA, 2017). Twelve of the proposed 124 projects are shoreline protection projects that include breakwater jetties with total projected costs of over $880 million (CPRA, 2017). Considering the potential impact and significant costs of these projects, it is vital that continued research such as this study be conducted to examine the effects and benefits of shoreline protection projects. Ideally, a well-designed breakwater jetty should prevent further land loss and promote land gain while simultaneously forming a healthy, natural and sustainable ecosystem surrounding the jetty. The data collected from this study can be incorporated into the design, planning and construction of breakwater jetties in an effort to optimize design construction for future projects.

Recommendations

I terms of trapping sediment behind the jetty, it appears that this jetty was built at an optimal height. During several weeks per years, tides generated from southerly or southeasterly winds are sufficient to overtop the jetty. Events such as these also churn up the benthos, causing the overtopped water to be sediment rich. Once behind the jetty, the waters slow down, enabling the sediment to drop out. We are not aware of any other jetty that has trapped sediment and built land at such a rapid pace.

NOAA suggests that fish dips should be 20 feet wide and located at least every 1000 feet of jetty. Fish dips in the current jetty are located every 1000 feet, but they range in width from 8 feet to 30 feet. The widest fish dips have created the most erosion of land and the narrowest the least. Furthermore, the propensity to close is unrelated to width. Therefore, if wetland gain is a primary goal of the project, as it should be, we suggest that future fish dips should be constructed narrower than 20 feet; a 10-foot width is recommended.

LITERATURE CITED

Allen, J. A., Pezeshki, S. R., & Chambers, J. L. (1996). Interaction of flooding and salinity stress on baldcypress (Taxodium distichum). *Tree Physiology*, *16*(1–2), 307–313.

Barnard, T. (1993). Coastal Shoreline Defense Structures. Virginia Institute of Marine Science Publication Center.

Batker, D., de la Torre, I., Costanza, R., Swedeen, P., & Day, J. W. (2010). Gaining Ground: Wetlands, Hurricanes and the Economy; The Value of Restoring the Mississippi River Delta. Earth Economics Project Report.

Britsch, L. D., Dunbar, J. B., Britscht, L. D., & Dunbart, J. B. (1993). Land Loss Rates : Louisiana Coastal Plain. *Journal of Coastal Research*, *9*(2), 324–338.

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, *47*(1), 26–35.

Chen, Q. J., Chakrabarti, A., Karmipour, A., & Johnson, C. (2016). Optimizing the Design of Shoreline Protection to Reduce Marsh Edge Erosion Based on Integrated Field Observations and Modeling. *Production & Operations Management*, *25*(7), 59.

Chesney, E. J., Baltz, D. M., & Thomas, R. G. (2000). Louisiana Estuarine and Coastal Fisheries and Habitats : Perspectives from a Fish's Eye View. *Ecological Applications*, *10*(2), 350–366.

Conner, W. H., & Inabinette, L. W. (2005). Identification of salt tolerant baldcypress (Taxodium distichum (L.) Rich) for planting in coastal areas. *New Forests*, *29*(3), 305–312.

Couvillion, B. R., Barras, J. A., Steyer, G. D., Sleavin, W., Fischer, M., Beck, H., Heckman, D. (2011). Land Area Change in Coastal Louisiana from 1932 to 2010. US Geological Survey.

Cowan Jr., J. H., Deegan, L. A., & Day, J. W. (2014). Fisheries in a Changing Delta. In *Perspectives on the Restoration of the Mississippi Delta*.

CPRA. (2011). Louisiana Coastal Facts. Baton Rouge, LA: Coastal Protection and Restoration Authority of Louisiana.

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

Day, J. W., Shaffer, G. P., Britsch, L. D., Hawes, S. R., 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.

Glasby, T. M., & Connell, S. D. (1999). Urban Structures as Marine Habitats. *Ambio*, *28*(7), 595–598.

Guidetti, P., Bussotti, S., & Boero, F. (2005). Evaluating the effects of protection on fish predators and sea urchins in shallow artificial rocky habitats: A case study in the northern Adriatic Sea. *Marine Environmental Research*, *59*(4), 333–348.

HDR. (2011). Tangipahoa Parish Lake Pontchartrain Shoreline Protection Project 95% Design Report, (138996).

Jerabek, A., Darnell, K. M., Pellerin, C., & Carruthers, T. J. B. (2017). Use of Marsh Edge and Submerged Aquatic Vegetation as Habitat by Fish and Crustaceans in Degrading Southern Louisiana Coastal Marshes. *Southeastern Geographer*, *57*(3), 212–230.

Krauss, K. W., Chambers, J. L., Allen, J. A., Soileau, D. M., Debosiert, A. S., & Survey, T. S. G. (2000). Growth and Nutrition of Baldcypress Families Planted Under Varying Salinity Regimes in Louisiana, USA. *Journal of Coastal Research*, *16*, 153–163.

Krauss, K.W., Shaffer, G.P., Keim, R.F., Chambers, J.L., Wood, W.B., and Hartley, S.B., (2017), Performance measures for a Mississippi River reintroduction into the forested wetlands of Maurepas Swamp: U.S. Geological Survey Scientific Investigations Report 2017–5036, 56 p., accessed September 28, 2018, at https://doi.org/10.3133/ sir20175036.

Mitsch, W. J. and J. G. Gosselink. (2015). Wetlands, 5th Edition. Wiley. 736p.

Penland, S., Wayne, L., Britsch, D., Williams, S. J., Beall, A. D., & Butterworth, V. (2001). Geomorphic Classification of Coastal Land Loss between 1932 and 1990 in the Mississippi River Delta Plain, Southeastern Louisiana. US Geological Survey.

Reed, D., & Wilson, L. (2004). Coast 2050: A New Approach to Restoration of Louisiana Coastal Wetlands. *Physical Geography*, *25*(1), 4–21.

Saucier, R. T. (1968). Recent Geomorphic History of the Pontchartrain Basin. *LSU Historical Dissertations and Theses*, 108.

Shaffer, G. P., Day, J. W., Mack, S., Kemp, G. P., van Heerden, I., Poirrier, M. A., … Penland, P. S. (2009a). The MRGO Navigation Project: A Massive Human-Induced Environmental, Economic, and Storm Disaster. *Journal of Coastal Research*, *10054*, 206–224.

Shaffer, G. P., Hoeppner, S., Howell, S., Benard, H., & Parsons, A. C. (2003). *Ecosystem Health of the Maurepas Swamp : Feasibility and Projected Benefits of a Freshwater Diversion*.

Shaffer, G. P., Wood, W. B., Hoeppner, S. S., Perkins, T. E., Zoller, J., Kandalepas, D., … Zoller, Jason Kandalepas, D. (2009b). Degradation of Baldcypress – Water Tupelo Swamp to Marsh and Open Water in Southeastern Louisiana , U.S.A. : An

Irreversible Trajectory? *Journal of Coastal Research*, *54*(Geological and Environmental Dynamics of the Pontchartrain Basin), 152–165.

Shaffer G.P., J.W. Day, D. Kandalepas, W.B. Wood, R. Hunter, R. Lane, and E. Hillman. 2016. Decline of the Maurepas Swamp, Pontchartrain Basin, Louisiana, and approaches to restoration. Water.

Thom, C. S. B., Peyre, M. K. G. L., & Nyman, J. A. (2004). Evaluation of nekton use and habitat characteristics of restored Louisiana marsh. *Ecological Engineering*, *23*(2), 63–75.

Turner, R. E., & Rabalais, N. N. (1991). Changes in Mississippi River water quality this century: Implications for coastal food webs. *BioScience*, *41*(3), 140–147.

USGS. (2002). Environmental Atlas of Lake Pontchartrain. United States Geological Survey. Retrieved from http://pubs.usgs.gov/of/2002/of2006/ env-issues/change-rate-borgne.html

Vaselli, S., Bulleri, F., & Benedetti-Cecchi, L. (2008). Hard coastal-defence structures as habitats for native and exotic rocky-bottom species. *Marine Environmental Research*, *66*(4), 395–403.