Assessing Shoreline Change and Vegetation Cover Adjacent to Back-Barrier Shoreline Stabilization Structures in Georgia Estuaries

Katherine R. Wakefield

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ASSESSING SHORELINE CHANGE AND VEGETATION COVER ADJACENT TO BACK-BARRIER SHORELINE STABILIZATION STRUCTURES IN GEORGIA ESTUARIES

by

KATHERINE WAKEFIELD

(Under the Direction of Chester Jackson)

ABSTRACT

Anthropogenic stabilization of erosional shorelines by hard-armoring structures (including bulkheads and riprap structures) is used for protection of property, especially if buildings, historical monuments, cultural resources, or other infrastructure are present. The post-installation effects of shoreline stabilization structures on adjacent shorelines in the back-barrier marshes of coastal Georgia are a concern, and interest in living shorelines (soft-armoring structures) as erosion control devices has increased because of their use of natural materials and vegetation. AMBUR shoreline analysis software was used to calculate pre-and post-installation shoreline change rates of shorelines adjacent to riprap and bulkhead structures (riprap: pre= -0.29 m/yr, post= -0.003 m/yr; bulkhead pre= 0.09 m/yr, post= -0.17 m/yr; negative= erosion, positive= accretion). There was no significant difference between the post-installation shoreline change rates of the structures (Wilcoxon Rank Sum, p-value= 0.4), but individually there is erosion immediately adjacent to four of the structures after installation (the end-around effect). The shoreline change rates adjacent to riprap structures showed site-specific accretion of the shoreline adjacent to the structure (0.07 (±0.03) m/yr and 0.14 (±0.03) m/yr) and
needs more study to determine if this is a representative trend for this structure type. Vegetation percent cover, stem height, and stem densities were measured in addition to shoreline change rates. Analysis of vegetation showed similarities between shorelines adjacent to living shorelines and control sites (living shoreline stem height: 102.17 cm; control site stem height: 95.52 cm). There are significant differences in vegetation cover between riprap structures and the control sites (riprap structure percent cover: 70.83% (stdev= 28%), p-value 0.0003 compared to control sites (Wilcoxon Rank Sum), riprap structure stem density: 56.33 (stdev= 28.72) cm, p-value <0.0001 compared to control sites), and these results showed that installation of riprap structures significantly changes the vegetation cover of the adjacent, unprotected shorelines. These results provide novel methodologies and initial data for determining the influence of erosion control structures on back-barrier shorelines, but it is unclear how much influence historical anthropogenic activities such as boat traffic have played a role with shoreline erosion in the study sites. The researcher identified limitations with available data sets so they may be changed moving forward to improve future research on back-barrier shoreline study. The results from these studies may allow for better informed decision making about the effects of shoreline stabilization structures on adjacent shorelines.

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by

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B.S., University of the South, 2013

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ASSESSING SHORELINE CHANGE AND VEGETATION COVER ADJACENT TO BACK-BARRIER SHORELINE STABILIZATION STRUCTURES IN GEORGIA ESTUARIES

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# TABLE OF CONTENTS

**CHAPTER 1**  
Introduction and Background .......................................................................................................................... 13

- Coastal Marshes ............................................................................................................................................ 13
- Shorelines and Shoreline Protection ........................................................................................................... 15
- Threats to Coastal Areas ............................................................................................................................... 18
- Georgia Back-BARRIER ............................................................................................................................... 19
- Previous Research ......................................................................................................................................... 20
- Purpose ......................................................................................................................................................... 22
- References .................................................................................................................................................. 25

**CHAPTER 2**  
Introduction ...................................................................................................................................................... 39

- Marshes as Buffers ...................................................................................................................................... 41
- Threats to Marsh Shorelines ......................................................................................................................... 42
- Shoreline Stabilization ................................................................................................................................. 43
- The Georgia Coast ....................................................................................................................................... 44
- Recent Shoreline Change Research ............................................................................................................ 47

**PURPOSE AND HYPOTHESES** .................................................................................................................. 49

**METHODOLOGY** .......................................................................................................................................... 50

- Site Determination ...................................................................................................................................... 50
- Site Descriptions ......................................................................................................................................... 52
- Calculating Shoreline Change ..................................................................................................................... 53

**RESULTS** .................................................................................................................................................... 56
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCUSSION</td>
<td>59</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>65</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>67</td>
</tr>
<tr>
<td>CHAPTER 3</td>
<td>114</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>116</td>
</tr>
<tr>
<td>IMPORTANCE OF MARSHES AND MARSH VEGETATION</td>
<td>116</td>
</tr>
<tr>
<td>THREATS TO MARSHES</td>
<td>118</td>
</tr>
<tr>
<td>GEORGIA SHORELINE STABILIZATION</td>
<td>120</td>
</tr>
<tr>
<td>PURPOSES AND HYPOTHESES</td>
<td>123</td>
</tr>
<tr>
<td>METHODOLOGY</td>
<td>125</td>
</tr>
<tr>
<td>SITE SELECTION</td>
<td>125</td>
</tr>
<tr>
<td>SITE DESCRIPTIONS</td>
<td>128</td>
</tr>
<tr>
<td>VEGETATION COVER ANALYSIS</td>
<td>130</td>
</tr>
<tr>
<td>RESULTS</td>
<td>133</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>135</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>140</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>141</td>
</tr>
<tr>
<td>CHAPTER 4</td>
<td>183</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>183</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.1: List of imagery and pre-existing shorelines used in this project. ..........74
Table 2.2: List of shoreline structures used in this project. ..................................75
Table 2.3: The raw pre-installation change rates (m/yr) for all of the transects calculated for the shoreline change rate study. ..........................................................76
Table 2.4: The raw post-installation change rates (m/yr) for all of the transects calculated for the shoreline change rate study. ..........................................................77
Table 2.5: Table of shoreline change rate comparisons ...........................................78
Table 2.6: The mean pre-installation EPRs (m/yr) for the shorelines of interest (1930, 1970) with errors. ..................................................................................79
Table 2.7: The mean post-installation EPRs (m/yr) for the shorelines of interest (1970, 2013) with errors. ..........................................................79

Table 3.1: Vegetation study site location information.........................................148
Table 3.2: Vegetation sampling dates per site.........................................................149
Table 3.3: Table of vegetation plots sampled within each area of interest plot.....150
Table 3.4: The raw values for the vegetation percent cover, stem height, and stem density analyses..............................................................................151-152
Table 3.5: The average values and standard deviations for the vegetation percent cover, stem height, and stem density analyses..................................................153
Table 3.6: The p-values for the post-hoc Wilcoxon Rank Sum comparisons for the vegetation percent cover, stem height, and stem density analyses .........................154
**Table 3.7:** The mean pre-installation end-point rates (m/yr) for shorelines immediately adjacent to hard-armoring shoreline stabilization structures in Georgia estuaries...155

**Table 3.8:** The mean post-installation end-point rates (m/yr) for shorelines immediately adjacent to hard-armoring shoreline stabilization structures in Georgia estuaries...156
LIST OF FIGURES

Figure 1.1: Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization....31
Figure 1.2: Kench (2015) in Pitfalls of Shoreline Stabilization.........................32
Figure 1.3: Diagram of bulkhead with rock toe protection. ............................33
Figure 1.4: Mason et al. (2016) in Pitfalls of Shoreline Stabilization..................34
Figure 1.5: Estuarine shoreline stabilization structures as designated by the Georgia
Department of Natural Resources Coastal Resources Division. ........................35
Figure 1.6: Diagram of the end-around effect...................................................36
Figure 1.7: Analysis of shorelines for shoreline change rates ............................37
Figure 1.8: A map of erosional hotspots on the Georgia coast, Jackson (2015). ....38

Figure 2.1: Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization...81
Figure 2.2: Mason et al. (2016) in Pitfalls of Shoreline Stabilization..................82
Figure 2.3: Kench (2015) in Pitfalls of Shoreline Stabilization............................83
Figure 2.4: Salt marsh area in Georgia. .........................................................84
Figure 2.5: Estuarine shoreline stabilization structures as designated by the Georgia
Department of Natural Resources Coastal Resources Division. ........................85
Figure 2.6: Diagram of bulkhead with rock toe protection .................................86
Figure 2.7: Diagram of the end-around effect..................................................87
Figure 2.8: Analysis of shorelines for shoreline change rates ...........................88
Figure 2.9: Site map of shoreline change rate study sites.................................89
Figure 2.10: Shoreline change analysis site “Bryan Structure 5”.......................... 90
Figure 2.11: Shoreline change analysis site “Camden Structure 2”...................... 91
Figure 2.12: Shoreline change analysis site “Glynn Structure 1 Plot 1”............... 92
Figure 2.13: Shoreline change analysis site “Glynn Structure 1 Plot 2” .......... 93
Figure 2.14: Shoreline change analysis site “Chatham Structure 2 Plot 1”. ...... 94
Figure 2.15: Shoreline change analysis site “Chatham Structure 2 Plot 2”. ....... 95
Figure 2.16: Shoreline change analysis site “Chatham Structure 4” ................. 96
Figure 2.17: Shoreline change analysis site “Chatham Structure 5 Plot 1”. ........ 97
Figure 2.18: Shoreline change analysis site “Chatham Structure 5 Plot 2”. ....... 98
Figure 2.19: Progression of shoreline preparation for analysis. ...................... 99
Figure 2.20: A compilation of the regressions of the EPRs (m/yr) for all of the riprap structure plots (68 transects, 6 plots, 3 structures)................................................. 100
Figure 2.21: The regression of the EPRs (m/yr) for Bryan structure 5 plot 1, the northwestern plot of Bryan structure 5......................................................... 101
Figure 2.22: The regression of the EPRs (m/yr) for Bryan structure 5 plot 2, the southeastern plot of Bryan structure 5......................................................... 102
Figure 2.23: The regression of the EPRs (m/yr) for Camden structure 2 plot 1, the southwestern plot of Camden structure 2.................................................. 103
Figure 2.24: The regression of the EPRs (m/yr) for Camden structure 2 plot 2, the northwestern plot of Camden structure 2. ................................................. 104
Figure 2.25: The regression of the EPRs (m/yr) for Glynn structure 1 plot 1, the northern plot of Glynn structure 1......................................................... 105
**Figure 2.26:** The regression of the EPRs (m/yr) for Glynn structure 1 plot 2, the southern plot of Glynn structure 1. .......................................................... 106

**Figure 2.27:** A compilation of the regressions of the EPRs (m/yr) for all of the bulkhead plots (68 transects, 6 plots, 3 structures). .......................................................... 107

**Figure 2.28:** The regression of the EPRs (m/yr) for Chatham structure 2 plot 1, the southwestern plot of Chatham structure 2. .......................................................... 108

**Figure 2.29:** The regression of the EPRs (m/yr) for Chatham structure 5 plot 2, the southeastern plot of Chatham structure 5. .......................................................... 109

**Figure 2.30:** The regression of the EPRs (m/yr) for Chatham structure 2 plot 2, the northeastern plot of Chatham structure 2 .......................................................... 110

**Figure 2.31:** The regression of the EPRs (m/yr) for Chatham structure 4 plot 1, the western plot of Chatham structure 4. .......................................................... 111

**Figure 2.32:** The regression of the EPRs (m/yr) for Chatham structure 4 plot 2, the eastern plot of Chatham structure 4. .......................................................... 112

**Figure 2.33:** The regression of the EPRs (m/yr) for Chatham structure 5 plot 1, the northwestern plot of Chatham structure 5. .......................................................... 113

**Figure 3.1:** Diagram of the end-around effect.................................................. 157

**Figure 3.2:** Salt marshes of Georgia................................................................. 158

**Figure 3.3:** Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization.. 159

**Figure 3.4:** Mason et al. (2016) in Pitfalls of Shoreline Stabilization............... 160
Figure 3.5: Estuarine shoreline stabilization structures as designated by the Georgia Department of Natural Resources Coastal Resources Division. ........................................ 161

Figure 3.6: Diagram of bulkhead with rock toe protection ........................................ 162

Figure 3.7: The vegetation study site locations. .......................................................... 163

Figure 3.8: Vegetation cover analysis site “City of Savannah Riprap” relative to the surrounding area ........................................................................................................... 164

Figure 3.9: Vegetation cover analysis site “City of Savannah-Bonaventure Cemetery” relative to the surrounding area ............................................................................................................. 165

Figure 3.10: Vegetation cover analysis site “Jekyll Island Marina Boat Ramp” relative to the surrounding area ........................................................................................................... 166

Figure 3.11: Vegetation cover analysis site “Little St. Simons Island Berolzheimer Dock Fill” relative to the surrounding area ............................................................................................................. 167

Figure 3.12: Vegetation cover analysis site “UGA Marine Research Institute” relative to the surrounding area ........................................................................................................... 168

Figure 3.13: Vegetation cover analysis site “UGA SklO” relative to the surrounding area ......................................................................................................................... 169

Figure 3.14: Vegetation cover analysis site “Little St. Simons Island Living Shoreline” relative to the surrounding area ........................................................................................................... 170

Figure 3.15: Vegetation cover analysis site “Sapelo Living Shoreline North” relative to the surrounding area ........................................................................................................... 171

Figure 3.16: Vegetation cover analysis site “Sapelo Living Shoreline South” relative to the surrounding area ........................................................................................................... 172

Figure 3.17: Progression of shoreline preparation for analysis .................................... 173
Figure 3.18: Vegetation transect and sampling plot layout .................. 174

Figure 3.19: Vegetation cover analysis “control site 1” relative to the surrounding area
............................................................................................................................................................................. 175

Figure 3.20: Vegetation cover analysis “control site 2” relative to the surrounding area
..................................................................................................................................................................................................................................... 176

Figure 3.21: Vegetation cover analysis “control site 3” relative to the surrounding area
..................................................................................................................................................................................................................................... 177

Figure 3.22: Vegetation cover analysis “control site 4” relative to the surrounding area
..................................................................................................................................................................................................................................... 178

Figure 3.23: Vegetation cover analysis “control site 5” relative to the surrounding area
..................................................................................................................................................................................................................................... 179

Figure 3.24: The average vegetation percent cover adjacent to the structures and the control sites with standard deviations .................................................................................................................. 180

Figure 3.25: The average vegetation stem heights adjacent to the structures and the control sites with standard deviations .................................................................................................................. 181

Figure 3.26: The average vegetation stem density adjacent to the structures and the control sites with standard deviations .................................................................................................................. 182
CHAPTER 1

Introduction and Background

Coastal areas are popular places to live and are frequented by people for a number of recreational and commercial activities. Property owners located adjacent to the shoreline sometimes face potential land loss due to erosion and often place structures like seawalls or other erosion control devices to reduce the threat of erosion. Shoreline stabilization structures can be used on erosive shorelines to prevent property loss and protect structures behind or adjacent to the shore, they can be used to keep waterways open for navigational purpose, and they can be used to prevent loss of recreational beaches. While the influence of erosion control devices on beachfront shorelines is well documented, the influence of these stabilization structures on back-barrier marsh and upland shorelines is not. The following projects studied the pre- and post-installation shoreline change rates on the shorelines immediately adjacent to a stabilization structure on an erosional shoreline and the associated vegetation cover.

Coastal Marshes

Tidal marshes are important and complex habitats that are sheltered from energetic open ocean processes. Tidal creeks in marshes provide a refuge for many economically important coastal organisms such as shrimp, oysters, clams, and many species of fish (Cowart et al., 2010; MacKenzie and Dionne, 2008; Shervette and Gelwick, 2008). They provide sheltered nursery habitat from larger fishes, which promotes the growth of young fish and crustaceans such as the red drum (*Sciaenops ocellatus*) and the blue crab (*Callinectes sapidus*) (Stunz et al., 2002; van Montfrans et al., 1995; Boesch and Turner, 1984). Estuaries and their surrounding marshes also
provide ecosystem services such as coastal protection, recreation, raw materials, and carbon and pollution sequestration (Barbier et al., 2011, McLeod et al., 2011).

By dissipating the wave and tidal energy on the upland areas, tidal marshes protect these areas on which infrastructure are built from erosion, flooding, and storm surge. (Kirwan and Megonigal, 2013; Mattheus et al., 2010; Leonard and Reed, 2002; Moller and Spencer, 2002). Wave dynamics are determined by factors such as wind speed, duration, fetch, and the local topography of the seabed (Davies and Johnson, 2006). Waves scour the shoreline and, depending on factors such the influx of sediment or the presence of vegetation, the shoreline can erode, accrete, or remain dynamically stable in its movements. The sediment size, texture, and composition are important characteristics of shoreline environments and determine the ability of the shoreline to withstand eroding forces.

Marshes are built and sustained by upstream sediments, and this allows them to act as a chemical buffer by sequestering pollutants and surplus nutrients from upstream systems (Cowart et al., 2010; Doney, 2010; Frey and Basan, 1985). The sediments flow downriver and flocculate sequestering pollutants from the water column before they flow into the larger offshore system (Syvitski et al., 2005; Victor et al., 2004; Wolanski and Spagnol, 2000). These flocs then settle, allowing the sediment to act as a pollution sink. (Leggett et al., 1995; Guene and Winnet, 1994; Williams et al., 1994; Oldfield et al., 1993; Valette-Silver, 1993;). Vegetation presence is essential to marsh stability and vertical accretion. The roots of vegetation provide scaffolding for the substrate and the stems decrease water velocity and promote the precipitation of suspended sediments in the water column. They also provide organic material that aids in building and
sustaining the marsh. The vegetation acts as a buffer to wave energy, and the marsh sediments are then able to withstand the moderate erosive wave action because of the critical erosion threshold of the silty marsh sediments (Tooley, 1992; Adam, 1990).

Marsh systems of Georgia include salt marsh, brackish marsh, and tidal fresh marshes. Salt marshes are the predominant type of marsh on the Georgia coast and are found in areas with salinities of 20ppt (parts per thousand parts water) or greater and are denoted by the presence of halophytic plant species, particularly smooth cordgrass (*Spartina alterniflora*) and black needle rush (*Juncus roemerianus*) (Morris et al., 2002; Adam, 1990). The perennial grass *S. alterniflora* dominates lower elevation salt marshes of coastal Georgia because of its ability to survive the frequent flooding regime (Pennings et al., 2005). *S. alterniflora* can be found as the tall phenotype in the low marsh adjacent to the water, and can be found as the short form in the middle marsh (Proffitt et al., 2003). Salt marshes are inundated regularly by the tides, and experience stresses related to salt tolerance and desiccation. The brackish marshes include a greater variety of vegetation because of the decreased salinity, which ranges from 0.5-20ppt, and it is dominated by *J. roemerianus*. The freshwater marshes have the lowest salinity, ranging from 0-0.5ppt, and *Zizaniopsis milaecea* is abundant in these areas (Craft et al., 2009).

**Shorelines and Shoreline Protection**

Approximately 60% of the entire world’s population lives on or near the coast (Houston, 2003; Lindeboom, 2002). According to NOAA and the US Census Bureau, in 2010 more than half of the population of the United States lives in coastal watershed counties, and most of the coastal counties of the Southeast experienced a population
growth of at least 10% (Mackun and Wilson, 2011). This percentage will continue to rise because the average number of people moving to these coastal watershed counties has been increasing (NOAA, 2013). Therefore, the protection of developed coastal areas is a concern because these populated areas are subject to coastal hazards such as shoreline erosion, hurricanes, and tidal flooding. Continuing to build infrastructure adjacent to changing shorelines poses financial risks to property owners and concerns of the potential impacts of developed property or anthropogenic activities on the surrounding environmental landscapes. An understanding of how coastal development might impact the surrounding landscape is important to improving policies for the management of these areas (Howard et al., 2011; Houston, 2003).

To protect property, investments, and infrastructure from potential erosion, landowners and managers attempt to stabilize these areas using erosion control structures. These stabilization structures can either be perpendicular or parallel to the shoreline, and structures can fall into the categories of hard-armoring, soft-armoring, or hybrid structures. Groins and jetties are two types of shoreline stabilization structures that are built perpendicular to the shoreline in an effort to trap sediment moving in the alongshore current, and they are considered hard-armoring structures (Figure 1.1). Comprised of piles of large rock (cobbles to boulder sized), groins are used on the beachfront to protect beaches and prevent washout of the beach, and jetties are used to keep navigable inlets such as bay entrances and river mouths open. Bulkheads and seawalls are vertical hard-armoring structures installed parallel to the shoreline to prevent erosion of the land immediately behind the structure (Figure 1.2). These structures often include a rock toe, or a pile of rocks, at the foot of the structure to
prevent washout of sediment at the base (Figure 1.3). Revetments and riprap structures (Figure 1.4 and 1.5b) are structures that are also parallel to the shoreline, but they are graded structures made of rubble (typically rock) piled against the shoreline. Living shoreline structures are considered soft-armoring or hybrid structures. Living shorelines are built parallel to the shoreline and use naturally occurring materials (e.g., oyster shells on the Georgia coast) and vegetation (Figure 1.5c) to stabilize the shorelines instead of entirely artificial materials. From Maryland to Florida, living shoreline methods are becoming increasingly popular. In Virginia and Maryland, the preferred method involves replanting intertidal and marsh vegetation behind a sill of sand, stone, or gabions (wire cages) of stones (Subramanian et al., 2013). On the Georgia coast, the most used method to date is using bags of cleaned oyster shells placed on the eroding shoreline with rebar stakes as reinforcement.

The Georgia Department of Natural Resources Coastal Resources Division (Ga DNR CRD) allows three types of structures that can be used in back-barrier estuarine shoreline environments: bulkheads, riprap structures, and living shorelines (Karl Burgess- personal communication, Ga DNR CRD, Figure 1.5). Bulkheads and riprap structures are considered hard-armoring structures because they include the use of artificial materials. Bulkheads are vertical structures composed of wood, concrete, steel, or vinyl, and they are not meant to withstand direct wave attack (Nordstrom, 2014; Alexander, 2010). Many of these structures also have a rock toe at their base that protects the structure from scouring which could compromise the integrity of the structure. Riprap structures are similar to beachfront revetments in that they are made of rock or rubble that are not vertical. Conversely, the living shoreline structures take
advantage of the surrounding habitat and utilize naturally occurring materials (i.e. using oyster shells and replanting vegetation) so they are not considered hard-armoring structures. Engineers who design these structures consider physical properties (e.g. geology, soil stability, tidal flow) of the area to estimate the stability of the structure, but may not account for the ecology and biology of the area (Houston, 2003), and increased erosion immediately adjacent to a structure after the structure’s installation is a concern. This effect is known as the end-around effect, and has been documented on shorelines adjacent to shoreline stabilization structures (Figure 1.6; Mason et al., 2016; Jackson, 2010).

**Threats to Coastal Areas**

Although natural habitats are important for maintaining shoreline and coastal integrity, they can be impacted by anthropogenic activities and modification of the coast (Halpern et al., 2008; Syvitski et al., 2005). Coastal ecosystems are some of the most threatened worldwide because of anthropogenic impacts, losing up to 7% every year (Pendleton et al., 2012; McLeod et al., 2011). These impacts include damming of rivers which prevents natural sediment flow, dredging for the deepening of navigational channels that may release toxins and pollutants sequestered in the mud, and shoreline stabilization that may affect the natural movement of the shoreline immediately behind and adjacent to the stabilization method (Wolanski, 2007; Lotze et al., 2006; Worm et al., 2006; Houston, 2003; Lindeboom, 2002). Shoreline stabilization can also have detrimental effects on the ecosystems, including increasing turbidity, sediment flow, or enhancing erosion adjacent to the structure which can ultimately change or degrade the services provided by the area (Jackson, 2010; Syvitski et al., 2005; Victor et al., 2004).
Recent research suggests that the installation of shoreline stabilization structures, especially vertical ones such as bulkheads, adversely affect coastal ecosystems by decreasing biodiversity and abundance of organisms (Gittman et al., 2016; Myszewski and Merryl, 2016).

The rate of sea level rise has increased over recent history, with sea level having risen 0.19 m at a rate of 1.5-1.9 mm/yr from 1901 to 2010, and models are predicting up to a 0.85 m rise in sea level (rate of up to 16 mm/yr) by the year 2100 (IPCC, 2014). The current sea level rise rate for the Georgia coast is approximately 3.17 mm/yr based on data recorded at the Fort Pulaski tide gauge since 1935 (NOAA, 2016). Furthermore, it is estimate that 95% of the ocean area will experience sea level rise of some kind (Kopp et al., 2016; IPCC, 2014). Studies modeling sea-level rise using SLAMM (Sea Level Affects Marshes Model) show that intertidal habitat up may be reduced up to 70% in the next 100 years, with up to a 45% loss of salt marsh (Craft et al., 2006; Harley et al. 2006; Galbraith et al., 2002). Marshes maintain by vertically accreting sediment with the help of the associated vegetation, and if sea-level rise increases too quickly, the marshes will drown leading to marsh habitat loss (Kirwan and Megonigal, 2013).

**Georgia Back-Barrier**

The Georgia coast has approximately 160,000 hectares of marshland, and over 11,000 km of tidal creek, river, and beachfront shoreline (Ga DNR-CRD, 2015; Jackson, 2015). Shoreline stabilization structures have been placed along erosional sections of these shorelines to prevent shoreline erosion and property loss, and a number of beachfront studies in the literature show that stabilization structures may detrimentally
impact the adjacent, unprotected shorelines and the associated habitat (Brayshaw and Lemckert, 2012; Granja and Pinho, 2012). However, there has been minimal research regarding how shoreline stabilization structures impact the estuarine marsh and upland shorelines of back-barrier Georgia.

The total number of permitted shoreline structures on the Georgia coast is 3161, and these are installed on back-barrier upland and oceanfront environments. Of these structures, 208 are labeled as riprap structures and 289 are labeled as bulkhead structures that are found on back-barrier shorelines (Alexander, 2010). Currently, the Ga DNR CRD allows only bulkhead, riprap structures, and living shoreline structures to be built on back-barrier shorelines (Karl Burgess- Ga DNR-CRD, Personal Communication).

**Previous Research**

Recently software programs such as DSAS (Digital Shoreline Analysis System; Danforth and Thieler, 1992), SCARPS (Simple Change Analysis of Retreating and Prograding Systems; Jackson, 2004), and AMBUR (Analyzing Moving Boundaries Using R, Jackson 2010) have been created that accurately calculate shoreline change rates. The AMBUR R package was specifically created for highly curved shorelines, and it uses a baseline and transect method to determine change rates of shorelines (Figure 1.7, Jackson et al., 2012). The AMBUR R package has been used for shoreline analysis for the Ga DNR CRD, the South Carolina Department of Natural Resources (SC DNR), and the North Carolina Department of Environmental and Natural Resources (NC DENR), as well as being used for other applications worldwide.
While patterns of beachfront shorelines and their movements related to alongshore currents, waves, and stabilization structures is well documented, estuarine shorelines are being increasingly studied to determine their response to tidal currents and similar stabilization structures. Hall and Pilkey (1991) found that bulkheads on the beachfront had the narrower dry beach-widths and some stabilized areas had no beach at all. Revetments of gabion structures in Shishmaref, Alaska lead to an increase in shoreline erosion rates, especially on the downdrift edge of the structure in the direction of the alongshore current, and these rates were approximately twice the rate of comparable undeveloped, unarmored shorelines (Mason et al., 2016). Historically, quantifying oceanfront shoreline change was easier given their much simpler shapes versus highly curved tidal stream and back-barrier shorelines that require more rigorous methods of analysis (Jackson, 2015; Jackson, 2010). Cowert et al. (2010) used DSAS to calculate the shoreline change rate for Cedar Island, North Carolina and found that the average shoreline change rate for the island is -0.24 m/yr. Jackson (2013) calculated shoreline change rates for the estuarine shorelines of South Carolina using AMBUR and found an overall shoreline change rate of -0.11 m/yr (± 0.10 m/yr), with an average of -0.36 m/yr for the erosion-only shorelines.

The Georgia coast shorelines have been analyzed by Jackson (2015), and over 11,000km of shoreline of Georgia’s coastal counties were mapped during the project. Shoreline change rates were calculated using over 46,000 transects spaced at every 50 meters along the back-barrier and beachfront shorelines. The results from this study showed an overall net shoreline change rate (accretion & erosion shorelines combined) of -0.03 meters per year (±0.07 meters per year) for all shorelines. The mean rate of
erosion-only shorelines is -0.49 meters per year (±0.07 meters per year) with erosional hotspots occurring in Chatham, Liberty, and McIntosh counties (Figure 1.8, Jackson, 2015). These comprehensive data from Jackson (2015) show overall shoreline change rate trends for the Georgia coast, but the shoreline change related to shoreline stabilization structures on back-barrier shorelines has not yet been determined. The installation of shoreline parallel structures such as bulkheads and revetments often increases end-around erosion, the erosion of the shoreline immediately adjacent to the structure, especially on the downdrift or ebbdrift side of the structure (Jackson, 2010).

Research has shown that shoreline stabilization structures, especially bulkheads, can be detrimental to the flora and fauna of the adjacent shorelines (Gittman et al., 2016). Vertical structures such as seawalls and bulkheads especially have been found to decrease biodiversity and abundance of organisms, and that epibiotan communities (communities of organisms that live on the surface of the substrate) differ from those found on natural, non-structured shorelines (Lam et al., 2009; Bulleri and Chapman, 2004). The effects of shoreline stabilization structures on the flora of adjacent shorelines, including *Spartina alterniflora*, have only been documented in one short-term study. These results did not show a significant difference between the vegetation adjacent to seawalls and natural non-structured shorelines (Pontee, 2013). However, these results are inconclusive because of the limited number of studies available (Gittman et al., 2016).

**Purpose**

The first objective of this thesis was to determine the shoreline change rates adjacent to shoreline stabilization structures on estuarine shorelines in Georgia and
determine if the artificial stabilization efforts had a significant impact on the shoreline change rates of the shorelines immediately adjacent to them. Shoreline stabilization structures on the oceanfront can negatively influence the shoreline change rates of the adjacent shorelines, and has been assumed with little quantitative evidence that shoreline stabilizations structures on back barrier shorelines function the same way.

The structures used in this study were bulkhead and riprap structures. Historical aerial photos and maps were used that contained gap of at least 20 years for each time step where used to calculate shoreline change. Aerial imagery as well as previously digitized shorelines were used in the analyses to calculate the variability of shoreline change rates from the 1930’s through 2013. The pre-installation and post-installation shoreline change rates were calculated for the 50 meters of shoreline adjacent to the structures. The rates of shoreline change adjacent to the shoreline structure types (bulkheads and riprap structures) were then compared to determine the differences in shoreline change rates of the two types of structures.

The second part of the project utilized field collected vegetation sampling methods to determine how the installation of shoreline stabilization structures influences the presence of vegetation on the adjacent shorelines. Back-barrier shorelines are stabilized by vegetation, and the vegetation was expected to differ between the structures and the control sites due to the end-around effect that changed the natural erosion rates of the shorelines. The structures used in this study were bulkheads, riprap structures, and living shorelines. Vegetation type, percent cover, stem heights, and stem densities were recorded for plots along transects that ran perpendicular to the
structures for 50 meters, and these data were compared to determine any differences in vegetation cover adjacent to the structures.

The goal of this study was to provide a framework for future research on how estuarine shoreline stabilization structures influence the adjacent shorelines and vegetation. Furthermore, the researcher attempted to provide guidelines on data acquisition and analyze work flows to assist coastal managers with developing metrics and methodologies for assessing the potential impacts/success of shoreline structures. The ultimate goal was to further the understanding of how current shoreline stabilization practices impact the shoreline and surrounding habitat and quantify the results in a way that newer structures, such as living shorelines, might be evaluated to determine their viability. The results from this study will be used to determine which structures will be most useful for shoreline stabilization on erosional shorelines, and what potential impacts the installation of a shoreline stabilization structure will be. These results also quantify the end-around effect found adjacent to hard-stabilization structures, and how the vegetation cover differs adjacent to shoreline stabilization structures compared to natural shorelines. Shoreline property owners and those wanting to conserve and manage shorelines along marshes and uplands now have baseline data by which can assist with decisions regarding shoreline stabilization structures in the back-barrier of Georgia.

Chapters 2 and 3 and standalone chapters written following the style of the Journal of Coastal Research, and material from Chapter 1 may be reiterated in the introductions of the following two chapters.
References


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Fig. 1.1: Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.

Fig. 1.4: Aerial view of the Tweed River entrance (a) showing the location of the training walls and sand pumping jetty (*bottom left*) and the jetty structure (b) (Source: NSW LPMA and QLD DERM 2011)
Fig. 1.2. Range of structures used to manage shoreline erosion. (a) Coral block seawall used as breakwater for harbor. (b) Coral block quay wall in harbor. (c) Concrete wall over stacked sandbag seawall. (d) Tetrapod seawall, Malé. (e) Arrangement of groynes on island shoreline. (f) and (g) Breakwaters on reef edge. (h) Sand pumping to reclaim land. A similar technique is adopted to nourish beaches.

**Figure 1.2:** Kench (2015) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 1.3: Diagram of bulkhead with rock toe protection. U.S. Army Corps of Engineers.
Fig. 5.3  Comparative photographs of 1980s concrete block revetment, upper as failed in 1992, lower, replaced in 1993

**Figure 1.4:** Mason et al., (2016) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 1.5: Estuarine shoreline stabilization structures as designated by the Georgia Department of Natural Resources Coastal Resources Division. A) bulkhead at Plum Orchard on Cumberland Island, B) riprap structure on the coast of South Carolina, and C) living shoreline on Little St. Simons Island.
Figure 1.6: Diagram of the end-around effect. The original shoreline is denoted by the brown dotted line, and the shoreline influenced by the end-around effect is denoted by the solid green line.
Figure 1.7: Analysis of shorelines for shoreline change rates. A) shorelines prepped for analysis (green line - year 1 shoreline, red line - year 2 shoreline), B) merged shorelines for buffer analysis (yellow), C) 10 meter buffer around shorelines to create baselines (pink), D) baselines generated for AMBUR analysis (purple), E) transects spaced every 5 meters that run from the shoreward baseline (light blue) to the streamward baseline (dark pink) and intersect the shorelines, F) distances between the intersection points classified as erosional (red) or accretional (blue) if the shoreline change was positive or negative, respectively.
Figure 1.8: A map of erosional hotspots on the Georgia coast, Jackson (2015).
CHAPTER 2
Shoreline Change Rates Adjacent to Two Types of Back-Barrier Shoreline Stabilization Structures and their Comparison

ABSTRACT

Installation of shoreline stabilization structures on erosional shorelines in the back-barrier of Georgia protects the environments and properties immediately behind the structure, but few researchers have studied the influence of these structures on the adjacent, non-armored shorelines. Through GIS-based analyses of shoreline change on areas immediately adjacent to hard-armoring structures (riprap structures and bulkheads), pre- and post-installation shoreline change rates have been calculated and compared. There was no significant difference in the pre-installation shoreline change rates between the two structures (riprap= -0.29 m/yr, bulkhead= 0.09 m/yr; Wilcoxon rank sum p-value= 0.4), and there was no significant difference between the pre- and post-installation shoreline change rates of the two types of structures (Wilcoxon rank sum p-value= 0.7, 0.7). Although, there was a pattern of increased erosion adjacent to the bulkheads and increased accretion adjacent to the riprap structures. Comparing the post-installation shoreline change rates of the two structures showed no significant difference (riprap= -0.003 m/yr, bulkhead= -0.17 m/yr; Wilcoxon rank sum p-value= 0.4), but the bulkhead adjacent shorelines showed relatively higher erosion rates than the riprap-structure-adjacent shorelines. Although the group comparisons were not significant, the individual regressions of four plots (1 riprap structure plot and 3 bulkhead plots) showed distinct end-around effects that support the idea that erosion increases immediately adjacent to shoreline stabilization structures after their installation. These
results provide information regarding the behavior of back-barrier shorelines after the installation of an erosion control structure, but further research is needed to determine the significance of these findings.
INTRODUCTION

Shoreline stability depends on abiotic and biotic factors. Abiotic factors such as wave and tidal action along with sea level rise are the main forces that shape the variable shorelines of estuarine systems (Mattheus et al., 2010). Biotic factors such as the presence and assemblage of vegetation assist in the stabilization and building of shorelines. The presence of vegetation allows for sediment stabilization through the presence of below ground biomass and the slowing of water velocity by the stems so that sediment may fall out of suspension (Allen and Pye, 1992; Adam, 1990; Stumpf 1983; Gleason et al., 1979). Property owners along the coast are often concerned about shoreline erosion, so they implement shoreline stabilization structures to prevent movement of the shorelines (Gittman et al., 2014). Shoreline stabilization structures are scrutinized because of their effects on the adjacent shorelines, and the current study calculated the shoreline change rates immediately adjacent to shoreline stabilization structures to determine how the installation of structures changes the shoreline change rates of the immediately adjacent shorelines.

Marshes as Buffers

Marshes are a physical buffer from wind and current activity, protecting upland areas and improving water quality (Cowart et al., 2010; Frey and Basan, 1985). The tidal marshes are sustained by sediments flowing from upstream catchments, (Syvitski et al., 2005; Victor et al., 2004; Wolanski and Spagnol, 2000). These sediments flocculate and fall out of suspension, resulting in accretion, the addition of nutrients, and the sequestration of pollutants (Cowart et al., 2010; Doney, 2010; Leggett et al., 1995; Guene and Winnet, 1994; Williams et al., 1994; Oldfield et al., 1993; Valette-Silver,
The presence of vegetation increases sediment deposition and sequestration of nutrients and pollution by decreasing the water velocity, thereby allowing sediment to settle (Wolanski, 2007; Valiela and Cole, 2002; Boorman et al., 1998; Turner, 1993; Allen and Pye, 1992; Pethick, 1992; Adam, 1990; Stumpf, 1983; Gleason et al., 1979; Bridges and Leeder, 1976). The roots of vegetation provide scaffolding for the substrate and the stems decrease water velocity and promote the precipitation of suspended sediments in the water column. They also provide organic material that aids in building and sustaining the marsh. The vegetation acts as a wave energy buffer, and the marsh sediments are then able to withstand the moderate erosive wave action because of the critical erosion threshold of the silty marsh sediments (Tooley, 1992; Adam, 1990).

**Threats to Marsh Shorelines**

Sea level rise studies show an increase in the rate of sea level rise over recent history. From 1901 to 2010, sea level rose 0.19 m at a rate of 1.5-1.9 mm/yr, but now models are predicting up to a 0.85 m rise in sea level (rate of up to 16 mm/yr) by the year 2100. Since 1935, the tide gauge at Fort Pulaski, Georgia has recorded a rise in sea level of 3.17 mm/yr (NOAA, 2016). By these estimates, more than 95% of the ocean area will experience sea level rise of some kind (Kopp et al., 2016; IPCC, 2014). Studies modeling sea level rise using SLAMM (Sea Level Affects Marshes Model) show that intertidal habitat up may be reduced up to 70% in the next 100 years, with up to a 45% loss of salt marsh (Craft et al., 2006; Harley et al., 2006; Galbraith et al., 2002). Marshes maintain by vertically accreting sediment with the help of the associated
vegetation, and if sea-level rise increases too quickly, the marshes will drown leading to marsh habitat loss (Kirwan and Megonigal, 2013).

Human activities can affect marsh and estuarine systems and include the building of dams, deforestation, overgrazing, and agricultural practices which can increase the amount of sediment eroding from river catchments (Syvitski et al., 2005; Victor et al., 2004; Wolanski and Spagnol, 2000). Drainage for the expansion of infrastructure directly reduces the wetland area which changes the available habitat, and dredging of estuaries for navigational purposes can also be detrimental to wetlands by disturbing the sediments in which pollution could be sequestered (Winger et al., 1999). These activities may lead to acidification, vegetation and fish kills, and ecosystem wide changes due to changes in sedimentation (Wolanski 2007; Soukup and Portnoy, 1986). Degradation of coastal wetlands negatively impacts viable fisheries and their nursery habitats, and can also harm the filtration and detoxifying services provided by vegetation (Worm et al., 2006).

**Shoreline Stabilization**

Approximately 60% of the entire world’s population lives on or near the coast (Houston, 2003; Lindeboom, 2002). According to NOAA and the US Census Bureau, in 2010 more than half of the population of the United States lives in coastal watershed counties. This percentage will continue to rise because the average number of people moving to these coastal watershed counties has been 99 people per square mile since the 1970s (NOAA, Coastal Population Report). The protection of coastal areas has become increasingly important due to the building of infrastructure to accommodate the growing population and the fact that these areas are subject to coastal hazards such as
shoreline erosion, hurricanes, and tidal flooding. Continuing to build infrastructure so close to changing shorelines poses a threat financially to those involved (Houston, 2003).

To protect property, investments, and infrastructure, landowners and managers attempt to control and stabilize these areas. Structures used to stabilize shorelines can be grouped into hard-arming and soft- or hybrid-arming. Hard armoring structures can be divided into shoreline-perpendicular (groins and jetties; Figure 2.1) and shoreline-parallel (seawalls, revetments, bulkheads, and riprap structures; Figure 2.2 and 2.3). Hard-arming structures can be made from wood, aluminum, concrete, rock, and other materials. Soft-arming or hybrid structures are also called living shorelines and strive to utilize naturally occurring materials such as oysters or coral and can include replanting of vegetation. Property owners and coastal managers require more extensive, interdisciplinary data on the impact of shoreline stabilization structures on the shoreline change rates and vegetation cover in order to make the best decisions regarding the maintenance and conservation of the shoreline and the associated habitat (Houston, 2003). Interest in the effects of sea level rise and protection of habitats adjacent to estuarine shorelines grows, so does the need for determining the effect of shoreline stabilization structures on marsh and upland shorelines (Alexander, 2010).

**The Georgia Coast**

The Georgia coast lies at the apex of the South Atlantic Bight (SAB), the coastal arc between Cape Hatteras, North Carolina and Cape Canaveral, Florida (Figure 2.4). Coastal regions closer to the apex of the SAB possess higher tide ranges relative to the coastlines at the upper and lower extents the SAB. The semidiurnal tides of the
along the Georgia coast have a tidal range of 2-4 meters, which categorizes this area as mesotidal (NOAA, 2016; Hayes, 1994). Because of the hydrodynamics of coastal streams, tidal inlet systems, and prevailing wind patterns, the tidal creeks of the Georgia coast are ebb dominated and this produces erosional areas on the outer bends (cutbanks) of the meanders, especially on the “ebb drift” side of the meander curve (downstream half of the curve) (Jackson, 2010; Dermuren and Rodi 1986).

The Georgia coast includes an approximately 10 km wide band of marsh that extends the entire length of the 160 km coastline, bounded on the east side by barrier islands and on the west side by mainland Georgia, i.e., the back-barrier area (Figure 2.4). The Georgia marshes include salt marsh, brackish marsh, and tidal fresh marsh along the estuarine salinity gradient. The salt marshes are found in areas with salinities of 20 practical salinity units (PSU) or greater and the vegetation is almost entirely a monoculture of *Spartina alterniflora* (Morris et al., 2002; Adam, 1990). The salt marshes are also inundated regularly by the tides, and experience stresses related to salt tolerance and desiccation (Pennings et al., 2005). The brackish marshes include a greater variety of vegetation because of the decreased salinity, which ranges from 0.5-20 PSU, but is dominated by *Juncus roemerianus* and *Spartina cynosuroides*, in the lower salinity marshes. The freshwater marshes of the Georgia coast have the lowest salinity, ranging from 0-0.5 PSU, and the highest vegetation species diversity of the marshes, with the dominant species being *Zizaniopsis miliacea* and *Typha latifolia* (Craft et al., 2009).

Shoreline stabilization structures are used to prevent erosion and property loss for coastal property owners. The Ga DNR CRD recognized three types of structures that
can be used in back-barrier estuarine shoreline environments: bulkheads, riprap structures, and living shorelines (Karl Burgess- personal communication, Georgia Department of Natural Resources Coastal Resources Division (Ga DNR CRD), Figure 2.5). Bulkheads and riprap structures are considered “hard-armoring” structures because they include the use of artificial materials. Bulkheads are vertical structures composed of wood, concrete, steel, or vinyl, and they are not meant to withstand direct wave attack (Nordstrom, 2014; Alexander, 2010). Many of these structures also have a rock toe at their base that protects the structure from scouring which could compromise the integrity of the structure (Figure 2.6). Riprap structures are similar to beachfront revetments in that they are made of rock or rubble that are not vertical. Conversely, the living shoreline structures take advantage of the surrounding habitat and utilize naturally occurring materials (i.e. using oyster shells and replanting vegetation) so they are not considered “hard-armoring” structures. Engineers who design these structures consider physical properties (e.g. geology, soil stability, tidal flow) of the area to estimate the stability of the structure, but may not account for the ecology and biology and could change or remove available habitat for the resident organisms (Houston, 2003).

Gittman et al. (2016) conducted a meta-analysis of the data available and found that shoreline stabilization structures, especially vertical structures such as bulkheads, detrimentally affect biodiversity and abundance of organisms. In order to protect not only the property immediately behind the structure but also the biota of the area, results like these should be more important when considering shoreline stabilization structuring options.
**Recent Shoreline Change Research**

Currently most of the information regarding the impact of shoreline stabilization structures on the surrounding shorelines and ecosystem comes from the study of beachfront shorelines (Nordstrom, 2014). These studies have produced results concerning the erosional effects that occur after the installation of the structures. Hall and Pilkey (1991) found that bulkheads on the beachfront had the narrowest beaches, some not having any beach at all. Revetments of gabion structures in Shishmaref, Alaska lead to an increase in the end-around erosion rates, especially downdrift of the structures, and these rates were approximately twice the rate of comparable undeveloped, unarmored shorelines (Mason et al., 2016). There is the potential for scouring out of shorelines adjacent to the structures due to the displacement of wave and current energy by the structure that occurs after its installation, and there is concern that this same scouring-out effect or end-around effect is occurring adjacent to stabilization structures along estuarine shorelines (Figure 2.7; Jackson 2010a).

Recently software programs such as DSAS (Digital Shoreline Analysis System; Danforth and Thieler, 1992), SCARPS (Simple Change Analysis of Retreating and Prograding Systems; Jackson, 2004), and AMBUR (Analyzing Moving Boundaries Using R, Jackson 2010b) have been created that accurately calculate shoreline change rates. The AMBUR R package was specifically created for highly curved shorelines, and it uses a baseline and transect method to determine change rates of shorelines (Figure 2.8, Jackson et al., 2012). The AMBUR R package has been used for shoreline analysis for the Ga DNR CRD and the South Carolina Department of Natural Resources (SC DNR) as well as being used for other applications worldwide.
Although shoreline change rate studies have previously focused on beachfront shorelines and structures in Georgia, recent focus has expanded to include extensive estuarine shorelines within Georgia’s coastal counties. Jackson (2015) mapped over 11,000km of both beachfront and back-barrier shorelines and calculated the overall shoreline change rate (including stabilized and non-stabilized shorelines) using over 46,000 transects along the shoreline spaced approximately 50 meters apart. The net shoreline change rate of -0.03 meters per year (±0.07 meters per year), and this net rate of change includes shorelines experiencing erosion and accretion (deposition). The mean rate of change for shorelines experiencing only erosion is -0.49 meters per year (±0.07 meters per year) with numerous erosional hotspots (rates exceeding -1 m/yr) occurring in Chatham, Liberty, and McIntosh counties near bays, inlets, and sounds (Jackson, 2015).
PURPOSE AND HYPOTHESES

The researcher attempted to answer the following questions: 1) Do post-installation shoreline change rates adjacent to shoreline stabilization structures found in back-barrier estuaries differ from pre-installation change rates over the time period between 1930 to 2013; and 2) Is there a difference between the shoreline post-installation change rates of shorelines adjacent to bulkheads compared to riprap structures? One hypothesis evaluated for this project was that the pre-installation shoreline change rates are the same for the shorelines adjacent to both structure types. Shoreline stabilization structures are used to prevent erosion immediately behind the structure, and the choice of structure does not depend on the calculated erosion rates of the shoreline. Another hypothesis evaluated for this project was that erosion rates increase on shorelines adjacent to shoreline stabilization structures after the structure’s installation. Based on qualitative observations in previous studies, the vertical nature of bulkheads may exacerbate the end-around effect, causing an increased erosion rate relative to riprap structures which typically are sloped. A final hypothesis is that shorelines adjacent to bulkheads have the same post-installation shoreline change rates as shorelines adjacent to riprap structures.

This chapter presents the results of the study of estuarine shoreline change rates immediately adjacent to shoreline stabilization structures. The two types of structures considered were riprap structures and bulkheads. The results provide quantitative measures of how shoreline change rates differ between the two types of structures, and how they compare to the current overall estuarine shoreline change rate of the Georgia coast.
METHODOLOGY

Site Determination

The purpose of this study was to determine shoreline change rates adjacent to shoreline stabilization structures (bulkheads and riprap structures) on back-barrier estuarine shorelines of the Georgia coast. Of the 129 bulkheads and riprap structures installed within the time frame (1980-1989) on the back-barrier shorelines of Georgia, only 6 were able to be used in the shoreline change rate analyses. Geomorphic characteristics and anthropogenic activities along the shorelines are varied and resulted in multiple case studies because no two sites were identical. Each case study focused on the historical shoreline change rate prior to the installation of the shoreline stabilization structure compared to the post-installation shoreline change rate of the structure. However, although the data available were limited after culling sites unsuitable for the study by the selection criteria, it was still possible to understand the general pattern or behavior of the shoreline adjacent to these structures.

The imagery and shapefiles used in this study are given in table 2.1. The Coastal Georgia Shoreline Structure Permit Shapefile (CGSSPS) from the Ga DNR CRD provided information regarding year of permitting, construction material, and GPS locations of the structures beginning in the 1970s. The CGSSS from the Applied Coastal Research Lab (ACRL) contains shoreline stabilization structures on the Georgia coast as of 2010 (Alexander 2010). There are discrepancies between the CGSSPS and the CGSSS regarding what is identified as a riprap structure and what is a revetment because the terminology used to identify the structure is specific to the location of the structure. According to the Ga DNR CRD, structures labeled as “riprap” structures
should not be found on the beachfront and structures labeled as “revetment” structures should not be found on back-barrier shorelines (Karl Burgess- personal communication).

There are over 3000 structures on the Georgia coast, and approximately 1700 of these have been delineated and ground-truthed in the GCSSS (Alexander, 2010). Only 1153 have been permitted since 1970 (GCSSPS). This project used structures permitted from 1980 through 1989 to ensure pre- and post- installation shoreline change rates could be calculated, and 129 structures were permitted during this time. Out of this group, structures in which there was overhanging vegetation for all of the imagery available were excluded due to the inability to accurately delineate the shoreline. Sites that were within 100 meters of another armoring structure were also excluded. This 100 meter buffer was determined by assuming a 50 meter “zone of influence” immediately adjacent to shoreline stabilization structures based on previous qualitative observations of shoreline stabilization structures in the back-barrier of the Georgia coast (Jackson 2010). This resulted in 35 stand-alone structures that were at least 100 meters from the next nearest structure that did not have tree overhang obscuring all of the imagery available.

Next, any of the 35 structures that did not have consistent labeling between the GCSSPS and the GCSSS were excluded from the study because it could not be determined if the structures were the same structure type or had been altered. This resulted in 13 structures being viable for use in the study. These 13 structures were verified through the Ga DNR CRD permitting files archives to determine the locations, materials, and modifications made to the structures of concern to ensure that they could
still be used in the study, and 9 of these structures were able to be verified. Of these 9 structures, only 6 had all of the pre- and post-installation shorelines and imagery needed to analyze shoreline change rates. The 6 structures are further divided into 3 riprap structures and 3 bulkheads (Figure 2.9).

**Site Descriptions**

The riprap structures were located Bryan, Camden, and Glynn counties and the bulkheads available for analysis were located in Chatham County (Figures 2.10-2.18). All structures were located on back-barrier tidal creeks or rivers and were upland or marsh adjacent. The structures with marsh beyond the extent of the structures include Glynn structure 1 (riprap structure, Figures 2.12 and 2.13), Chatham structure 2 (bulkhead, Figures 2.14 and 2.15), and Chatham structure 4 (bulkhead, Figure 2.16).

Bryan structure 5 is a riprap structure located in a residential area at 31.88706N -81.21976W and was permitted on October 23, 1980 (Figure 2.10). Camden structure 2 is also a riprap structure in a residential area located at 30.87196N -81.58231W and was permitted on August 30, 1988 (Figure 2.11). The final riprap structure, Glynn structure 1, is the Jekyll Island public boat ramp located at 31.04703N -81.42167W and was permitted on June 9, 1981 (Figure 2.12 and 2.13). The riprap structures are compiled of granite rubble and discarded concrete and brick. Chatham structure 2 a treated lumber bulkhead of the Skidaway Institute of Oceanography and is located at 31.9854N -81.02265W and was permitted on March 18, 1980 (Figures 2.14 and 2.15). Chatham structure 4 is the bulkhead structure for the Hutchinson Island coal terminal dock located at 32.09382N -81.09435W and permitted on March 9, 1982 (Figure 2.16). The final bulkhead structure is Chatham structure 5, is a structure for Global Ship
Systems located at 32.09844N -81.11196W, and was permitted on February 10, 1988 (Figures 2.17 and 2.18). The two bulkheads are made of concrete. The structure site name, latitude, longitude, common name, county, permit (conclusion) date, and project type are given in table 2.2.

Calculating Shoreline Change

To determine shoreline change rates immediately adjacent to the shoreline stabilization structures, area of interest (AOI) plots were created in Esri® ArcGIS™ version 10.2.1. The extent of the shorelines adjacent to the structures to be digitized was determined by creating 100 by 50-meter rectangular polygon features (AOI plots) that were placed adjacent to the structure. These features were then georeferenced and could be used on any available shoreline or imagery to standardize the 50 meters of interest. Their placement was perpendicular to a digitized line connecting the endpoint of the structure to a point 50 meters from the structure that lay on the shoreline (Figure 2.19). With the AOI plots were the shorelines on which the shoreline change rate analyses would be run (Jackson, 2010a).

Historical shorelines were delineated from georectified aerial photography and shorelines generated in previous studies by Jackson (2010b, 2015) were used to determine the pre- and post-installation shoreline change rates. The data were provided by the Skidaway Institute of Oceanography (SkIO), the United States Department of Agriculture Farm Service Agency (USDA FSA), the National Oceanic and Atmospheric Administration (NOAA), the Georgia Department of Natural Resources Coastal Resources Division (Ga DNR CRD), and the Applied Coastal Research Lab (ACRL) of Georgia Southern University (Table 2.1).
The shoreline from the 1930’s was provided by Dr. Chester W. Jackson Jr. at the ACRL. This shapefile has a horizontal accuracy of 5 meters or better, and was used to analyze the pre-installation shoreline change. The 1970’s imagery from SkIO had a resolution of 1 m per pixel and was acquired as non-georeferenced imagery in the tagged image file format (TIFF) files. An imagery set from 1972 was used as this was the year with the most coverage for the Georgia coast. When the coverage of the 1972 imagery was not complete, aerial imagery from 1976 was used. Following the georectifying protocol set by the ACRL, all of the non-georectified images from the 1970’s used in this study were georectified using a third order polynomial function with a minimum of 11 source points. The root mean squared value for the imagery was calculated to be below 1 meter for each TIFF. The Ga DNR CRD provided the most recent (2013/2014) digital orthophotos of the Georgia coast that were used in this study, and they are 1 meter per pixel in resolution with an accuracy of 2 meters or better. The accuracy of these datasets were determined by the Ga DNR CRD prior to their use in this project.

The digitization protocol of shorelines from imagery was the same as described in the North Carolina Division of Coastal Management’s mapping protocol (Geis and Bendell, 2008). Changes made to the protocol were the substitution of an “upland” designation for the shorelines that would otherwise be described as a “sediment bank” per the North Carolina protocol, and the inclusion of “trees” and “structure” as designations for shoreline classification. The shorelines used for the shoreline change rate analysis are shown in figures 2.10 through 2.18.
The shoreline change analysis program AMBUR was used to create transects at 5-meter intervals starting directly adjacent to the structure and extending to 50 meters from the structure along the shore. The shoreline change rates are calculated by a “transect” method in which transects were cast through all of the existing shorelines from baselines that follow approximately parallel to the shorelines (Figure 2.8). Calculating the differences between the transect intersection points gave the end point rate (EPR), the rate of change between the newest and the oldest shorelines (i.e. the “end points”). Using this methodology, shoreline change rates prior to the installation of the structure and after the installation of the structure were calculated to determine the influence of the structure on the adjacent shorelines. The mean EPR of the transects cast on each side of the structure were analyzed using the Wilcoxon rank sum test because of the small sample sizes. The parameters analyzed were the pre-installation shoreline change rates between the two types of structures, the pre-installation and post-installation shoreline change rates of each structure type, and the post-installation rates between the two types of structures. The individual EPR of each transect as distance from the structure increased (to 50 meters from the structure along the shoreline) were also analyzed using linear regressions.
RESULTS

The EPR calculations for the pre- and post-installation shoreline change rates of all of the transects for each of the sites are given in tables 2.3 and 2.4., and the mean of the post-installation shoreline change rates was -0.08 (stdev= 0.30). The shorelines within the AOI plots adjacent to all shoreline stabilization structures did not have significantly different shoreline change rates before the installation of the structures as calculated by AMBUR (Wilcoxon rank sum test, df=1, p-value= 0.4). There was no significant difference between the pre- and post-installation shoreline change rates of the riprap structures and the bulkheads (riprap structures: Wilcoxon rank sum test, df=1, p-value= 0.7; bulkheads: Wilcoxon rank sum test, df= 1, p-value= 0.7). There was also no significant difference between the post-installation change rates of the shorelines adjacent to bulkheads and shorelines adjacent to riprap structures (Wilcoxon rank sum test, df=1, p-value= 0.4). All Wilcoxon rank sum test p-values are given in table 2.5.

Although there were no significant differences between any of the comparisons of the groups, there were discernible patterns (Tables 2.6 and 2.7). Overall the shorelines adjacent to bulkhead structure sites had higher accretion rates during pre-installation time periods (0.70 ± 0.15, 0.00 ± 0.21, and -0.23 ± 0.12 mean EPR) than shorelines adjacent to riprap structure sites (0.52 ± 0.08, -0.93 ± 0.22, and -0.51 ± 0.09 mean EPR). The rates of shoreline change adjacent to the riprap structure sites were less erosional after the installation of shoreline stabilization structure (-0.20 ± 0.03, 0.07 ± 0.03, and 0.14 ± 0.03 mean EPR), and these accretion rates were overall higher than the rates for the shorelines adjacent to bulkheads (0.04 ± 0.03, -0.36 ± 0.03, and -0.19 ±
0.03), which were more erosional than the pre-installation shoreline change rates. The shorelines adjacent to bulkheads were overall more erosional than those adjacent to riprap structures.

The riprap structure shoreline change regressions show no significance as a group ($R^2 = 0.007$, p-value = 0.159; Figure 2.20); however, the structures do show unique patterns individually. The regression of plot 1 of Bryan structure 5 is the northwestern plot of the structure and demonstrates the end-around effect immediately adjacent to hard-armoring structures. The rate of change immediately adjacent to the structure is more erosive than the rate of change 50 meters from the structure (Figure 2.21). This is a significant pattern because the $R^2$ value is 0.593 with a p-value of 0.003. However, the regression of Bryan structure 5 plot 2 is the southeastern plot of the structure and does not show this same pattern (Figure 2.22, $R^2 = 0.0.126$, p-value of 0.257). Plot 1 of Camden structure 2 is the southwestern plot of the structure, and the $R^2$ value of the regression is 0.577 with a significant p-value of 0.007. The regression of the northeastern plot 2 of Camden structure 2 has an $R^2$ value of 0.206 with a p-value of 0.161. Although the regression pattern of Camden structure 2 plot 1 is significant, the erosion rates of Camden structure 2 plot 1 and 2 do not show the end-around pattern (Figure 2.23 and 2.24). Plot 1 of Glynn structure 1 is the northern plot and has an $R^2$ value of 0.397 with a p-value of 0.038, and plot 2 is the southern plot and has an $R^2$ value of 0.207 with a p-value of 0. 0.159 (Figures 2.25 and 2.26). Of the two plots, the southern plot 2 shows the end-around" effect, but this is not a significant pattern.

The bulkhead structure regressions also do not show no significance as a group ($R^2 = 0.003$, p-value= 0.657, Figure 2.27). However, there are significant trends for all of
the individual bulkhead plots except for plot 1 of Chatham 2 and plot 2 of Chatham 5 (Chatham structure 2 plot 1 p-value = 0.089, Figure 2.28; Chatham structure 5 plot 2 p-value = 0.262, Figure 2.29). The southwestern plot 1 of Chatham structure 2 regression has an $R^2$ value of 0.0288 with a p-value of 0.089 and shows no significant pattern, but the northeastern plot 2 regression has an $R^2$ value of 0.644 with a p-value of 0.002 (Figure 2.30). Plot 2 shows the end-around pattern where the erosion rates are higher immediately adjacent to the structure and lessen as distance from the structure increases, and this pattern is significant. The regression for Chatham structure 4 plot 1, the western plot, shows a significant end-around effect (Figure 2.31, $R^2$ = 0.891, p-value <0.001), as does the regression for the eastern plot, plot 2 (Figure 2.32, $R^2$ = 0. 0.527, p-value= 0.007). The regression of the eastern plot, plot 1, of Chatham structure 5 has an $R^2$ value of 0.736 with a p-value of <0.001 (Figure 2.33). The regression of the western plot, plot 2, of Chatham structure 5 has $R^2$ value of 0.0.137 with a p-value of 0.262 (Figure 2.29). Of these two regressions, Chatham structure 5 plot 1 shows a significant pattern, although it is not an end-around effect.
DISCUSSION

Shoreline stabilization structures are installed on shorelines to mitigate erosion on the property immediately behind the structure. Although the results of these shoreline change rate analyses are not significant, there are overall patterns adjacent to each of the two structure types. There are also individual patterns that support the presence of an end-around effect which is the increased erosion of the adjacent shoreline after the installation of a shoreline stabilization structure. This observation suggests that property owners and coastal managers should consider the implications of installing the structures and the potential for exacerbating erosion.

A primary hypothesis for this project was that pre-installation shoreline change rates of the shorelines studied would be the same as post-stabilization change rates of the same shoreline. Because different types of structures are used to stabilize erosional shorelines, answering this hypothesis also led to developing quantitative tests to determine if a bulkhead-type or riprap-type of structure would be a better option given the level of erosion. The type of structure installed is typically requested by the property owner, and riprap structures are often easier to install than bulkhead structures. This is because riprap structures are rocks and other debris piled on the shoreline whereas bulkheads typically require more rigorous construction methodologies being that they are vertical structures typically made of wood and metal. The results show that the shorelines of interest did not have significantly different shoreline change rates before the installation of the structures (Wilcoxon rank sum test, df= 1, p-value= 0.4). Therefore, the current conclusion is that both riprap structures and bulkheads are used
on shorelines experiencing similar shoreline change rates based on available shoreline datasets used in the study.

Another hypothesis for this project was that the erosion rates of shorelines adjacent to hard-armoring shoreline stabilization structures would increase after the installation of the structure. Granja and Pinho (2012) found that the construction of groins on Portuguese shorelines increased the rate of erosion downdrift of the structure. Brayshaw and Lemkert (2014) studied erosion downdrift of the mouth of the Tweed river on the Gold Coast of Australia and found that shoreline modification was one of the main drivers of the shoreline change. The installation of hard-armoring, shoreline parallel structures such as bulkheads and revetments often increases end-around erosion, the erosion of the shoreline immediately adjacent to the structure, especially on the downdrift or ebbdrift side of the structure (Jackson, 2010). In Shishmaref, Alaska, the installation of gabions and rip-rap type revetments lead to an increase in the end-around erosion rates, especially downdrift of the structures, and these rates were approximately twice the rate of comparable undeveloped, unarmored shorelines (Mason et al., 2016). Based on the analysis of the shorelines available for each of the 6 sites (1930, 1970, 2013) in the current study, the analyses did not show a significant difference between the riprap pre- and post-installation shoreline change rates and there is not a significant difference between the bulkhead pre- and post-installation shoreline change rates. The results provided by the current study did not support the hypothesis because there were no significant differences between the pre- and post-installation shoreline change rates for either the riprap-structure-adjacent sites or the bulkhead-adjacent sites.
Although there was no significant difference for the riprap-structure adjacent sites, a pattern of lessened erosion was documented for one of the sites, a change from erosion to accretion for another, and an increase in accretion for the final site. This was not the expected result for the shoreline change rates after the installation of a shoreline stabilization structure on a shoreline because previous studies have suggested the end-around effect. However, the previously discussed studies were beachfront studies whereas the riprap structures in this study were located in the back-barrier along tidal streams and rivers. The increase of accretion and decrease of erosion adjacent to the riprap structures could be due to the ebb and flood system of the tidal creeks as opposed to the alongshore current flowing in a dominant direction like that found on the beachfront.

The shoreline change rates of the bulkhead-adjacent shorelines show a pattern of increased erosion, although these findings were not significant, either. For the bulkhead-adjacent sites, one site showed a pattern of lessened accretion, another site showed a change from relatively stable to erosion, and the final site showed increased erosion. This was generally the pattern expected because studies have found that hard-armoring structures exacerbate the erosion downdrift of, or adjacent to the structure. The insignificance of this pattern could be due to the location of two of the bulkhead sites on the Savannah River. This river is an area of high commercial boat traffic, with the Port of Savannah being the fourth largest shipping terminal in the United States (Houser, 2011) and of possible undocumented shoreline stabilization structures that could have impacted the analyses of these shoreline change rates. These results suggest that the installation of a riprap structure on back-barrier shorelines may prevent
the exacerbated erosion of the end-around effect better than the installation of a bulkhead. However, more studies are needed to fully understand how the shorelines respond to each of the structures. Ultimately, future studies would benefit by incorporating more shoreline and structure data in order to improve statistical analyses and the determination of significance by increasing the number of sample sites.

The final hypothesis for this project was that the post-installation shoreline change rates of the shorelines adjacent to the riprap structures and bulkheads would be the same. The differences among the site comparisons of this study were not significant. However, qualitative observations show a pattern of shorelines adjacent to bulkheads and shorelines adjacent to riprap structures behaving differently. The pattern observed was that shorelines adjacent to bulkheads continued to erode and the shorelines adjacent to riprap structures accrete post-installation. This could be due to two of the riprap structures being located on tidal creeks with relatively little boat traffic and two of the bulkhead structures being located on the high-boat-traffic Savannah River. Again, the number of sites and locations studied needs to be increased if the overall influence of shoreline stabilization structures on shorelines is to be better understood, but the conclusion from these data is that although the results are not significant, there is a pattern of bulkhead-adjacent shorelines presenting the end-around effect more so than the riprap-structure adjacent shorelines.

The mean for the post-installation shoreline change rates was -0.08 (stdev=0.30). The average shoreline change rate for the entire Georgia coast is approximately -0.03 meters/year with an error of ±0.07 meters/year, and the overall shoreline change rate for estuarine shorelines is -0.04 meters/year (Jackson 2015). The erosion rate of
all of the post-installation shoreline transects measures was higher than the overall Georgia average as well as the estuarine shoreline only average. This was the assumed pattern because of the proposed end-around effect that was seen adjacent to some of the individual structures. Since this erosion rate is related to the presence of a stabilization structure, further research should be conducted to determine the influence of all of the current shoreline stabilization structures utilizing the presently calculated shoreline change rates for the Georgia coast. Since the average erosion rates adjacent to shoreline stabilization structures is slightly higher than the average shoreline change rates, the overall shoreline change rates should be corrected for the presence and number of shoreline stabilization structures that are currently installed on the coast.

The current sample size is too small to provide definitive results; therefore, further study is needed to determine more conclusive results. If the time frame were expanded to include more years, the sample size would be larger. The datasets available had never been used for a project such as this, and faults with the datasets were apparent after trying to determine sampling sites. Inconsistencies in the labeling between the two datasets and inaccurate plotting of GPS points were the two most outstanding problems with the datasets, with undocumented structures also increasing the difficulty of site selection. Furthermore, it is unclear how much influence historical anthropogenic activities such as boat traffic have played a role with shoreline erosion in the study sites.

The shorelines adjacent to the structures, if not structured themselves, are vital in protecting inland area from storm surge and sea-level rise because of the presence of marsh vegetation (Costanza et al., 2008; Moller and Spencer, 2002). These results
show that although the overall influence is not significant, some of the hard-armoring structures significantly change the erosion rates of the adjacent shorelines, and this could lead to the building of more shoreline stabilization structures on the adjacent shorelines. The ability of a shoreline to build and keep pace with sea-level rise is related to the presence of vegetation (Ferrario et al., 2014; Gedan et al., 2011). If the shorelines change too dramatically, which is possible with the influence of anthropogenic, hard-armoring erosion control devices, the inland areas lose the ecosystem services provided by the plant stems and belowground biomass, making them more susceptible to erosion, storm surge, and sea-level rise. With this pressure, it is important to understand how the installation of shoreline stabilization structures is affecting important coastal buffer zones and the economic and ecological losses will accrue (Pendleton et al., 2012; McLeod et al., 2011). New and innovative methods of stabilizing the shoreline such as soft-armoring strategies and living shoreline structures should be researched moving forward to understand if they have the same end-around effect or if they provide a more stable shoreline adjacent to the structure that may function like a non-structured shoreline.
CONCLUSION

As more people move to and utilize the coast, it is imperative to study how anthropogenic activities are impacting this economically and ecologically important area. The marshes and estuaries are critical in protecting upland and inland environments, and more information is needed to better manage and conserve these areas. The results show that the installation of a shoreline stabilization structure alters the shoreline change rates of the adjacent shorelines, and that there is a difference in how the shorelines respond to the installation of the different shoreline stabilization structures. The results will help supply needed information to coastal managers to make more informed decisions about the effects of shoreline stabilization structures on adjacent shorelines.

Through GIS-based analyses of changes of shorelines areas immediately adjacent to hard-armoring structures (riprap structures and bulkheads), pre- and post-installation shoreline change rates have been calculated and compared. There was no significant difference in the pre-installation shoreline change rates between the two structures, and there was no significant difference between the pre- and post-installation shoreline change rates of the two types of structures although there was a pattern of increased erosion adjacent to the bulkheads and increased accretion adjacent to the riprap structures. Comparing the post-installation shoreline change rates of the two structures showed no significant difference, but the bulkhead adjacent shorelines showed relatively higher erosion rate than the riprap-structure-adjacent shorelines. Although the group comparisons were not significant, the individual regressions of X number of sites showed a distinct end-around effects that support the idea that erosion
increases immediately adjacent to shoreline stabilization structures after their installation.

The results of the study suggest general trends of shoreline erosion rates and potential patterns adjacent to the shoreline stabilization structures pre- and post-installation given data limitations. The methodology proved useful for small scale shoreline change rate calculations, but issues lie with the data available. Without ground-truthing the shorelines, errors occur due to undocumented shoreline structures, incorrectly labeled or measured structures, and inconsistent labeling and documenting among datasets which could have led to inaccurate site selection. Finally, other anthropogenic activities that have historically taken place adjacent to the shorelines such as boat traffic need to be considered in future studies of possible impacts on erosion.
References


Jackson, C.W. Jr. 2015. Final Report: Mapping shoreline erosion and vulnerability along the Georgia coast 1800s to 2000s. Ga DNR CRD.

Karl Burgess- personal communication, Ga DNR CRD


Table 2.1: List of imagery and pre-existing shoreline used in this project.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data Source</th>
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<th>Accuracy (±m)</th>
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<td>1972 9&quot;X9&quot; Aerial Photography</td>
<td>Skidaway Institute of Oceanography</td>
<td>1 meter</td>
<td>3 meters</td>
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<tr>
<td>1976 9&quot;X9&quot; Aerial Photography</td>
<td>Skidaway Institute of Oceanography</td>
<td>1 meter</td>
<td>3 meters</td>
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<td>2 meters</td>
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<td>Georgia Department of Natural Resources Coastal Resources Division</td>
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<td>2010 Coastal Georgia Structure Shapefile</td>
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Table 2.2: List of shoreline structures used in this project.

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<th>Longitude</th>
<th>Common Name</th>
<th>County Name</th>
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<th>Project Type</th>
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<td>Camden</td>
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<td>Marsh and Upland</td>
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**Table 2.3:** The raw pre-installation change rates (m/yr) for all of the transects calculated for the shoreline change rate study. The mean shoreline change rate for all of the transects sampled is -0.11 (stdev= 0.70). The mean of the riprap-only sites is -0.29 (stdev= 0.64) and the mean of the bulkhead-only sites is -0.09 (stdev= 0.71).

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<th>Camden S2P2</th>
<th>Chatham S2P1</th>
<th>Chatham S2P2</th>
<th>Chatham S4P1</th>
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Table 2.4: The raw post-installation change rates (m/yr) for all of the transects calculated for the shoreline change rate study. The mean shoreline change rate for all of the transects sampled is -0.08 (stdev= 0.30), the mean of the riprap-only sites is -0.003 (stdev= 0.24) and the mean of the bulkhead-only sites is -0.17 (stdev= 0.33).

<table>
<thead>
<tr>
<th>Transect</th>
<th>Bryan S5P1</th>
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<th>Camden S2P1</th>
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<th>Chatham S2P1</th>
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Table 2.5: Table of shoreline change rate comparisons, Wilcoxon Rank Sum tests and their associated p-values (n=3 for all comparisons). None of the comparisons were significant.

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Table 2.6: The mean pre-installation EPRs (m/yr) for the shorelines of interest (1930, 1970) with errors.

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Table 2.7: The mean post-installation EPRs (m/yr) for the shorelines of interest (1970, 2013) with errors.

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<th>Structure</th>
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<th>Error</th>
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**FIGURES**

**Fig. 1.4** Aerial view of the Tweed River entrance (a) showing the location of the training walls and sand pumping jetty (*bottom left*) and the jetty structure (b) (Source: NSW LPMA and QLD DERM 2011)

**Figure 2.1:** Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 2.2: Mason et al., (2016) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 2.3: Kench (2015) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 2.4: Salt marsh area in Georgia. Shapefile courtesy of the U.S. Fish and Wildlife Service National Wetlands Inventory.
Figure 2.5: Estuarine shoreline stabilization structures as designated by the Ga DNR CRD: a) bulkhead at Plum Orchard on Cumberland Island), b) riprap structure on the coast of South Carolina), and c) living shoreline on Little St. Simons Island).
Figure 2.6: Diagram of bulkhead with rock toe protection, courtesy of the U.S. Army Corps of Engineers.
Figure 2.7: Diagram of the end-around effect. The original shoreline is denoted by the dashed brown line and the green line shows the shoreline as it is influenced by the end-around effect.
Figure 2.8: Analysis of shorelines for shoreline change rates. A) shorelines prepped for analysis (green line- year 1 shoreline, red line- year 2 shoreline), B) merged shorelines for buffer analysis (yellow), C) 10 meter buffer around shorelines to create baselines (pink), D) baselines generated for AMBUR analysis (purple), E) transects spaced every 5 meters that run from the shoreward baseline (light blue) to the streamward baseline (dark pink) and intersect the shorelines, F) distances between the intersection points classified as erosional (red) or accretional (blue) if the shoreline change was positive or negative, respectively.
Figure 2.9: Site map of shoreline change rate study sites. There are three bulkhead structures and three riprap structures.
Figure 2.10: Shoreline change analysis site “Bryan Structure 5” (riprap structure, permitting date 10/23/80, 31.88706N -81.21976) showing the shorelines used in the analysis.
Figure 2.11: Shoreline change analysis site “Camden Structure 2” (riprap structure, permitting date 8/30/88, 30.87196N -81.58231W) showing the shorelines used in the analysis.
Figure 2.12: Shoreline change analysis site “Glynn Structure 1 Plot 1” (riprap structure, permitting date 6/9/81, 31.04703N -81.42167W) showing the shorelines used in the analysis.
Figure 2.13: Shoreline change analysis site “Glyn Structure 1 Plot 2” (riprap structure, permitting date 6/9/81, 31.04703N -81.42167W) showing the shorelines used in the analysis.
Figure 2.14: Shoreline change analysis site “Chatham Structure 2 Plot 1” (bulkhead, permitting date 3/18/80, 31.9854N -81.02265W) showing the shorelines used in the analysis.
Figure 2.15: Shoreline change analysis site “Chatham Structure 2 Plot 2” (bulkhead, permitting date 3/18/80, 31.9854N -81.02265W) showing the shorelines used in the analysis.
Figure 2.16: Shoreline change analysis site “Chatham Structure 4” (bulkhead, permitting date 3/9/82, 32.09382N -81.09435W) showing the shorelines used in the analysis.
Figure 2.17: Shoreline change analysis site “Chatham Structure 5 Plot 1” (bulkhead, permitting date 2/10/88, 32.09844N -81.11196W) showing the shorelines used in the analysis.
**Figure 2.18:** Shoreline change analysis site “Chatham Structure 5 Plot 2” (bulkhead, permitting date 2/10/88, 32.09844N -81.11196W) showing the shorelines used in the analysis.
Figure 2.19: Progression of shoreline preparation for analysis. A) delineated shoreline stabilization structure (blue line), B) straight line between the endpoints of the structure (pink line), C) relative placement of polygons (orange rectangles) perpendicular to the structure endpoint line, D) heads-up digitization of shorelines that fall within the polygons (green line- year 1 shoreline, red line- year 2 shoreline).
Figure 2.20: A compilation of the regressions of the post-installation EPRs (m/yr) for all of the bulkhead plots (68 transects, 6 plots, 3 structures). The regression correlation is -0.08, (F-stat = 0.45; df = 1, 66; p-value = 0.51), showing no pattern among the regressions as a group.
Figure 2.21: The regression of the EPRs (m/yr) for Bryan structure 5 plot 1, the northwestern plot of Bryan structure 5. The regression correlation is 0.77, (F-stat = 14.57; df = 1, 10; p-value = 0.003).
Figure 2.22: The regression of the EPRs (m/yr) for Bryan structure 5 plot 2, the southeastern plot of Bryan structure 5. The regression correlation is -0.36, (F-stat = 1.445; df = 1, 10; p-value = 0.257).
Figure 2.23: The regression of the EPRs (m/yr) for Camden structure 2 plot 1, the southwestern plot of Camden structure 2. The regression correlation is -0.76, (F-stat = 12.28; df = 1, 9; p-value = 0.007).
Figure 2.24: The regression of the EPRs (m/yr) for Camden structure 2 plot 2, the northwestern plot of Camden structure 2. The regression correlation is 0.45, (F-stat = 2.332; df = 1, 9; p-value = 0.1611).
Figure 2.25: The regression of the EPRs (m/yr) for Glynn structure 1 plot 1, the northern plot of Glynn structure 1. The regression correlation is -0.63, (F-stat = 5.93; df = 1, 9; p-value = 0.038.)
Figure 2.26: The regression of the EPRs (m/yr) for Glynn structure 1 plot 2, the southern plot of Glynn structure 1. The regression correlation is -0.46, (F-stat = 2.35; df = 1, 9; p-value = 0.159).
Figure 2.27: A compilation of the regressions of the EPRs (m/yr) for all of the riprap structure plots (68 transects, 6 plots, 3 structures). The regression correlation is 0.05, (F-stat = 0.; df = 1, 66; p-value = 0.657), showing no pattern among the regressions as a group.
Figure 2.28: The regression of the EPRs (m/yr) for Chatham structure 2 plot 1, the southwestern plot of Chatham structure 2. The regression correlation is -0.54, (F-stat = 3.64; df = 1, 9; p-value = 0.089).
Figure 2.29: The regression of the EPRs (m/yr) for Chatham structure 5 plot 2, the southeastern plot of Chatham structure 5. The regression correlation is -0.37, (F-stat = 1.43; df = 1, 9; p-value = 0.262).
Figure 2.30: The regression of the EPRs (m/yr) for Chatham structure 2 plot 2, the northeastern plot of Chatham structure 2. The regression correlation is 0.80, (F-stat = 18.1; df = 1, 10; p-value = 0.002).
Figure 2.31: The regression of the EPRs (m/yr) for Chatham structure 4 plot 1, the western plot of Chatham structure 4. The regression correlation is 0.94, (F-stat = 73.49; df = 1, 9; p-value = <0.001).
Figure 2.32: The regression of the EPRs (m/yr) for Chatham structure 4 plot 2, the eastern plot of Chatham structure 4. The regression correlation is 0.73, (F-stat = 11.16; df = 1, 10; p-value = <0.007).
Figure 2.33: The regression of the EPRs (m/yr) for Chatham structure 5 plot 1, the northwestern plot of Chatham structure 5. The regression correlation is -0.86, (F-stat = 25.06; df = 1, 9; p-value = <0.001).
CHAPTER 3

Comparison of Vegetation Presence Adjacent to Shoreline Stabilization Structures

ABSTRACT

The vegetation on back-barrier shorelines is a critical buffer for inland areas from the effects of storm surge and sea level rise. The effects of the different structures on the marsh shoreline vegetation were quantified, and the results show that the control sites and the living shoreline sites were the most similar with regard to vegetation percent cover, stem heights, and stem densities. The comparisons of percent covers were significantly different among all of the comparisons except for between the living shoreline sites and the control sites. The stem height results showed similarities between shorelines adjacent to living shorelines and control sites (living shoreline stem height: 102.17 cm; control site stem height: 95.52 cm). There were significant differences in vegetation percent cover between riprap structures and the control sites (riprap structure percent cover: 70.83%, p-value 0.0003 compared to control sites percent cover 96.89%, riprap structure stem density: 56.33 stems/m², p-value <0.0001 compared to control sites stem density: 40.6 stems/m²), and these results showed that installation of riprap structures significantly changes the vegetation percent cover of the adjacent, unprotected shorelines. Stem densities were highest for the riprap structures and bulkheads (56.33 stems/m² and 49.23 stems/m², respectively). These results show that the vegetation adjacent to riprap structures were shorter and had a lower percent cover than the vegetation found on the control sites, and the vegetation presence adjacent to living shoreline structures is similar to that of the control sites. These results
suggest that the living shorelines are currently most similar to the natural environment, and these findings will assist property owners and managers to make more informed decisions about erosion stabilization devices.
INTRODUCTION

Back-barrier marshes are an important buffer for inland areas where coastal populations are settled because they provide protection from wave activity and storm surge (Barbier et al., 2011; McLeod et al., 2011). The presence of vegetation lessens erosive wave activity and promotes the settling out of sediment for marsh accretion, and it stabilizes the existing sediment through below ground biomass (Adam, 1990). The installation of shoreline stabilization structures can alter the change rates of the adjacent shorelines, in turn changing the natural presence of vegetation (Mason et al., 2016; Jackson, 2010). This change in vegetation on adjacent shorelines after the installation of a shoreline stabilization structure could exacerbate the already erosive nature of the shoreline. The hard-armoring shoreline stabilization structures currently used on back-barrier shorelines have come under scrutiny as interest in the threat of sea-level rise and the subsequent shoreline protection increases. Soft-armoring or hybrid alternatives are being more widely used without quantitative comparison to their hard-armoring counterparts. Understanding how hard-armoring structures are changing the vegetation on the adjacent shorelines and how the newer soft-armoring structures compare is critical when considering how these stabilized shorelines will continue protecting the inland areas and how they will respond to sea-level rise.

Importance of Marshes and Marsh Vegetation

By dissipating the tidal surge and wave influence on the upland areas, tidal marshes protect upland areas from erosion, flooding, and storm surge (Kirwan and Megonigal, 2013; Mattheus et al., 2010; Leonard and Reed, 2002; Moller and Spencer, 2002). Wave dynamics are determined by factors such as wind speed, duration, fetch,
and the local topography of the seabed (Davies and Johnson, 2006). Waves scour the shoreline and the shoreline can erode, accrete, or remain dynamically stable depending on factors such as the influx of sediment or the presence of vegetation.

Vegetation presence provides essential ecosystem services and is essential to marsh stability and vertical accretion. The vegetation of marshes provides carbon and pollution sequestration as well as protection of inland areas and upland and marsh shorelines from erosion (Barbier et al., 2011; McLeod et al., 2011). The roots of vegetation provide scaffolding for the substrate and the stems decrease water velocity and promote the precipitation of suspended sediments in the water column. The roots and stems also provide organic material that aids in building and sustaining the marsh. The vegetation acts as a wave energy buffer, and the marsh sediments are then able to withstand the moderate erosive wave action because of the critical erosion threshold of silty marsh sediments (Tooley, 1992; Adam, 1990).

Marsh systems of Georgia include salt marsh, brackish marsh, and tidal fresh marshes along the estuarine salinity gradient from upland to coast. Salt marshes are the predominant type of marsh on the Georgia coast and are found in areas with salinities of 20 practical salinity units (PSU) or greater and are denoted by the presence of halophytic plant species, particularly smooth cordgrass (*Spartina alterniflora*) and black needle rush (*Juncus roemerianus*) (Figure 3.2; Morris et al., 2002; Adam, 1990). The perennial grass *S. alterniflora* dominates lower elevation salt marshes of coastal Georgia because of its ability to survive the frequent flooding regime (Pennings et al., 2005). This species exhibits phenotypic plasticity related to nitrogen availability that manifests in a dwarf form that reaches 40 centimeters and a tall form which reaches up
to 3 meters (Morris, 1982; Smart, 1982). The tall form is found immediately adjacent to the creek or river where the elevation is the lowest, and the short form is found higher in the marsh (Proffitt et al., 2003; Gallagher et al., 1988). Salt marshes are inundated regularly by the tides, and experience stresses related to salt tolerance, flooding, and desiccation (Pennings et al., 2005). The brackish marshes, with a salinity ranging from 0.5-20 PSU, include a greater variety of vegetation than the salt marsh but are dominated by *J. roemerianus*, and the freshwater marshes have the lowest salinity, ranging from 0-0.5 PSU, and *Zizaniopsis milaecea* is abundant in these areas (Craft et al., 2009).

**Threats to Marshes**

The installation of anthropogenic structures can change the shoreline change rates of the adjacent shorelines (Jackson, 2010; Pilkey and Wright, 1988), and can possibly change the presence of vegetation. Anthropogenic shoreline stabilization structures can also provide novel habitat and change the species diversity of the area (Barbier, 2011; Lotze et al., 2006). A phenomenon termed the “end-around effect” has been observed adjacent to estuarine shoreline stabilization structures, but this effect has not been quantitatively researched in detail (Jackson, 2010). This end-around effect is the scouring out of the adjacent shoreline due to the redirection of wave and current forces after the installation of a shoreline stabilization structure (Figure 3.1). This effect can influence the vegetation on the shorelines because it can exacerbate erosion adjacent to the structures (Mason et al., 2016; Jackson, 2010). Since vegetation is integral to maintaining substrate stability, increased erosion and subsequent loss of vegetation can increase the likelihood of shoreline degradation.
Estuarine shorelines are influenced by anthropogenic activities such as the building of infrastructure for increasing coastal populations, dredging of waterways for navigational purposes, and building of dams that can change the sedimentation dynamics of rivers and creeks (Halpern et al., 2008; Wolanski, 2007; Lotze et al., 2006; Worm et al., 2006; Houston, 2003; Lindeboom, 2002). These activities can change the morphology of the marsh and shoreline change rates through increasing or decreasing the sedimentation that sustains the marshes, ultimately leading to artificial stabilization of estuarine shorelines by structures to preserve property and maintain the stability of the changing shorelines (Wolanski, 2007; Sylvestre et al., 2005). Although shoreline stabilization structures are used widely among all shoreline types, most of what is known about the impacts of these structures on the local geomorphology and ecology comes from oceanfront studies (Pilkey et al., 2009; Houston, 2003; Landry et al., 2003; Harmsworth and Long, 1986). Recent literature review has shown that there is a lack of data regarding the impact of shoreline stabilization structures on vegetation presence (Gittman et al., 2016). As more structures are permitted for installation on the coast, environmental managers and property owners are beginning to consider the impacts on the ecosystem instead of only focusing on stabilization structures fronting a property.

Sea level rise is a concern as studies show an increase in the rate of sea level rise over recent history (IPCC, 2014; Miller et al., 2005). Models for future sea level rise predict an increase in sea level for up to 95% of the ocean area within the next 100 years, with sea level rising up to 0.82 meters (IPCC 2014). The sea level rise predicted for the Georgia coast is between 2-3 meters over the next century (2-3 mm/yr; NOAA 2016b). Sea level is dependent on many factors including growth and decay of ice
sheets, thermal expansion and contraction of seawater, and variations in sedimentation (Miller et al., 2005). Rising sea level may result in salt marsh transgression, which may cause conversion of brackish and freshwater marshes to salt marsh (Craft et al., 2006). Sea-level rise and the potential installation of shoreline armoring to protect existing and future coastal development and properties could reduce intertidal habitat up to 70% in the next 100 years (Harley et al. 2006; Galbraith et al., 2002). The ability of the marsh to accrete at a rate to keep up with sea-level rise is regionally dependent, and requires the presence of vegetation to slow water velocity to allow suspended sediment to fall out as well as belowground biomass that provides subsurface expansion and organic matter (Doney, 2010).

**Georgia Shoreline Stabilization**

The structures used for shoreline stabilization on the Georgia coast fall into two categories: hard-armoring and soft-armoring structures. Hard-armoring structures are those that use artificial materials to stabilize the shoreline, and soft-armoring or hybrid structures are those that include methods that regrade the shoreline, replant vegetation, install bags of cleaned oyster shells for the propagation of an oyster reef, or utilize geotextiles such as coconut fiber to prevent sediment erosion (Ga DNR CRD, 2013). Structures used to stabilize shorelines can be grouped into hard-armoring and soft- or hybrid-armoring. Hard armoring structures can be divided into shoreline-perpendicular (groins and jetties; Figure 3.3) and shoreline-parallel (seawalls, revetments, bulkheads, and riprap structures; Figure 3.4). Hard-armoring structures can be made from lumber, aluminum, concrete, rock, and other materials. Soft-armoring or hybrid structures are also called living shorelines and strive to utilize naturally occurring materials such as
oysters or coral and can include replanting of vegetation. Bulkheads and riprap structures are the labels given to vertical and graded structures on back-barrier shorelines, respectively (Karl Burgess at Ga DNR CRD- Personal Communication, Figure 3.5). Bulkhead structures are vertical structures that are made of wood, aluminum, or concrete. They often have a rock toe or toe protection at the base of the structure for support and to prevent washout (Figure 3.6). The riprap structures are graded structures that use large rocks and rubble piled on the shoreline for stabilization (Nordstrom, 2014; Alexander, 2010). Living shorelines are a soft-armoring shoreline option that are used on back-barrier shorelines for restructuring or stabilization. The North Carolina DNR has installed living shorelines that include re-grading and replanting of marsh shorelines, and the GA DNR CRD has recently installed living shorelines composed of bags of cleaned oyster shells that are believed to not only provide shoreline stabilization but also substrate on which oyster spat can recruit and build oyster reef.

Living shorelines have become popular on the southeastern coast and are beginning to be installed along the Georgia coast (Myszewski and Alber, 2016). Living shorelines are intended to be shoreline erosion control techniques that mimic naturally occurring habitat while providing ecosystem services such as improving water quality and providing area for increased local species diversity (GA DNR, 2013). North Carolina has been implementing these structures over the past decade with a focus on oyster restoration especially in the Pamlico Sound, and South Carolina is also using living shorelines as not only shoreline protection but oyster restoration habitat (Myszewski and Merryl, 2016; Pace and Boyd, 2012). Interest in these structures has
increased and there is a need to determine how living shorelines (soft-armoring/hybrid structures) compare to hard-armoring structures in terms of their influence on the erosion rates and vegetation on adjacent shorelines as definitive results have not been quantified. Studies have shown that the installation of hard-armoring erosion control structures often increase the erosion rates immediately adjacent to the structures (Mason, 2016; Jackson, 2010), but the influence of soft-armoring structures like living shorelines on the adjacent shoreline vegetation is unknown. Hard-armoring structures continue to be installed, but the possible benefits of soft-armoring structures such as carbon sequestration, storm surge dampening, and provision of habitat for naturally occurring species cannot be ignored. The living shorelines on the Georgia coast have only been installed since 2010, so this research sets a foundation for future study of these shoreline stabilization structures.
PURPOSES AND HYPOTHESES

The goal of this project was to answer the following questions: 1) How do shoreline stabilization structures influence the vegetation percent cover, stem height and stem density on adjacent shorelines, and how does this vegetation compare to vegetation on non-structured shorelines? and 2) How does the vegetation differ among living shorelines and “hard-armoring” shorelines? One hypothesis for this project was that vegetation percent cover is lower adjacent to shoreline stabilization structures compared to erosional shorelines with no shoreline stabilization structure. Vegetation presence depends on the stability of the shoreline, and qualitative observation of shorelines adjacent to shoreline stabilization structures shows an increase in shoreline instability and erosion immediately adjacent to the structure after installation (Jackson, 2012). Another hypothesis for this project was vegetation stem heights and stem densities on shorelines adjacent to hard-armoring shoreline stabilization structures (bulkhead and riprap structures) are lower than those found adjacent to control sites. Hard-armoring shoreline stabilization structures have been criticized by some coastal scientists for being damaging to the shoreline due to process such as the end-around effect that increases erosion. It has been suggested that soft-armoring or hybrid approaches such as living shorelines do not have the same effect, and are thus able to sustain the tall S. alterniflora stems found immediately adjacent to tidal creeks in the low marsh (Proffitt et al., 2003).

This chapter presents the results of the study of vegetation on estuarine shorelines adjacent to shoreline stabilization structures and on control sites. Field vegetation sampling methods were used to determine the influence of the shoreline
stabilization structures on the vegetation percent cover, stem height, and stem density on the adjacent shorelines. The results provide quantitative measures of how vegetation presence differs among bulkheads, riprap structures, living shorelines, and control sites.
METHODOLOGY

In order to determine how shoreline stabilization structures affect the adjacent shoreline vegetation cover, a sampling universe was created from the datasets available. The major dataset used to begin creating the sampling universe was the Coastal Georgia Shoreline Structure Permit Shapefile (CGSSPS) from the Georgia Department of Natural Resources Coastal Resources Division (Ga DNR CRD). The CGSSPS from the Ga DNR CRD provided information regarding year of permitting, construction material, and GPS location of the structures beginning in the early 1970’s.

Site Selection

Only bulkheads, riprap structures, and living shorelines permitted between 1980 and 2010 were used in this analysis to determine stabilization structure impact on shoreline vegetation. This time frame was chosen so that the following results would parallel with previously calculated shoreline change rate analyses of similar structures. Imagery from 2013 GA DNR CRD digital orthoimagery (1 meter per pixel, 2 meter horizontal accuracy) was used to determine the feasibility of traveling to, locating, and physically reaching a site under reasonable conditions. These conditions were that the researcher would be able to sample the vegetation in the area solitarily without running risking hurting one’s self, becoming stuck or trapped, or otherwise entering into a dangerous situation to a degree that would entail calling for assistance. Tree overhang and adjacent shoreline discernibility were not of concern because all of the sites were visited and the imagery data were ground-truthed. The ground truthing allowed the researcher to determine the shoreline under the overhanging trees. It was qualitatively determined that the influence of shoreline stabilization structures on the shoreline
extended up to 25 meters from the structure, so the area of interest was then doubled for this study (Jackson: personal communication, 2014). Only structures that were isolated from any other structure by at least 100 meters on either side were used for this study to ensure minimal influence of other structures on the structures of interest. Structures that were found in dense residential or privately owned areas were excluded because of possible undocumented structures within close proximity to the structure of interest. Preliminary visits to sites determined that areas of private land ownership sometimes had undocumented structures that were not discernable in aerial imagery, so for the sake of expediency in site selection and in order to utilize resources and time efficiently, areas where there was the possibility of an undocumented structure being present were excluded. Of the 150 shoreline structure sites permitted between 1980 and 2013, only 8 structures fit the criteria (Figure 3.7, Table 3.1). Each of these structures was visited twice from March through June, and the habitat type of the adjacent shorelines were documented and digitized (Figures 3.8-3.16). The shorelines and habitat types were digitized using a modified NC mapping protocol (Geis and Bendell, 2008).

Area of interest (AOI) plots for shorelines adjacent to shoreline stabilization structures were created in Esri® ArcGIS™ version 10.2.1. The extent of the shorelines adjacent to the structures to be visited was determined by creating 100 by 50-meter rectangular polygon features (AOI plots) that were placed adjacent to the structure. These features were then georeferenced and could be used on any available shoreline shapefile or imagery to standardize the 50 meters of the shoreline of interest. Their placement was perpendicular to a digitized line connecting the endpoint of the structure
to a point 50 meters from the structure that lay on the shoreline. These digitized plots were used to standardize the visual area of interest adjacent to the structures when viewing the aerial imagery in ArcGIS for site selection, and also provided a visual for the on-the-ground extent of shoreline to be sampled.

In the field, transects were cast at every 5 meters along the plot boundaries, resulting in a 30 by 50-meter grid that was the on-the-ground equivalent of the digitized AOI plots. The sample points for the vegetation data were at the intersection of these transects (Figure 3.18). The pattern expected from this layout was that transects A, B, and C would fall on upland sites, D would follow the shoreline, and E, F, and G would lie in the marsh and the associated tidal creek. Due to standardizing the positioning of the AOI plots, the grids did not follow this pattern exactly. Each transect had 11 sample points (shore parallel) spaced at 5 meter intervals, point 1 being immediately adjacent to the structure and point 11 being 50 meters from the structure to provide an overview of the vegetation presence adjacent to the structures. Sample site D1 is the sample site immediately adjacent to the edge of the structure and lies on the shoreline. In some cases, this point is located on upland, and in others this point is located in the marsh depending on where the edge of the structure was located. The entirety of transect D rarely followed the mean high water line because of the crenulated shape of the shoreline and the fact that the transect was cast as a straight line from D1 to D11. For the habitat cover analysis, the habitat type (upland, marsh, or tidal creek) were determined for each intersection point. The transect methods used to determine vegetation cover adjacent to tidal creeks is adapted from Currin et al. (2008).
Site Descriptions

The control sites were chosen in the same manner as the structure sites; however, priority was given to sites that were near the shoreline stabilization structure sites for ease of access. The control sites were chosen based on their isolation from developed and residential areas, accessibility of the researcher to reach the sites unaided, and for their ability to be reached without significant risk of the researcher putting herself in a dangerous situation. The 5 control sites were all located on Little St. Simon’s island on the outer meander bend of a tidal creek (control site 1= 31.241436N - 81.304214W, Figure 3.19; control site 2= 31.242053N -81.304069W, Figure 3.20; control site 3= 31.242514N -81.303342W, Figure 3.21; control site 4= 31.243864N -81.302586W, Figure 3.22; and control site 5= 31.257683N -81.301544W, Figure 3.23). The habitat cover of the AOI plots of the control sites are given in table 3.1. Control sites 1 and 4 had the highest percent of marsh (49% and 48%, respectively), while Control sites 2, 3, and 5 had equal or greater percentages of upland than marsh (upland: 38%, 25%, and 52% respectively; marsh: 17%, 25%, and 8%, respectively). All of the control sites had similar percent tidal creek cover (40%-50%). The researcher found in some preliminary site visits to potential control sites that there was an influence of undocumented shoreline stabilization structures on the sites of interest due to incomplete or non-existent data. Other research into shoreline change and shoreline stabilization structure or re-nourishment projects have also run into similar issues (Kana, 2012), so in order to ensure pristine control sites, all 5 control sites were located on Little St. Simon’s Island. Although this did not provide conclusive, Georgia-coast
wide control results, it did provide a baseline completely free from anthropogenic shoreline stabilization efforts that until now has not been provided.

The three riprap structures were located on the tidal creek adjacent to the Bonaventure Cemetery in Savannah, Georgia (32.048N -81.03944W, permitting date 04/02/90, Figure 3.8; 32.04266N -81.04308W, permitting date 08/14/2003, Figure 3.9), and immediately beside the public boat ramp on Jekyll Island (31.04703N -81.42167W, 06/09/81, Figure 3.10). These structures were made of large granite boulders piled on the shoreline and allowed to settle at a grade less than 45º (Clover, 1995). There was a deposition of marble tombstones of undetermined age at the northern Bonaventure Cemetery site. There were also cinder blocks and bricks of undetermined age included at both of the Bonaventure Cemetery sites. The habitat cover of the AOI plots of the riprap structures are given in table 3.1. The riprap structures had relatively low tidal creek habitat percent covers (0-9%) and relatively high marsh habitat percent covers (31-47%).

The three bulkheads were located on Little St. Simons Island (31.24856N -81.30444W, permitting date 08/10/90, Figure 3.11), Sapelo Island at the UGA Marine Institute (31.43611N -81.28055W, permitting date 02/17/84, Figure 3.12), and Skidaway Island at the UGA Marine Institute (31.9854N -81.02265W, permitting date 03/18/80, Figure 3.13). All of the bulkheads included vertical installations of treated lumber. The habitat cover of the AOI plots are given in table 3.1. The bulkhead structures have similar percent covers of marsh (15-42%), but the Little St. Simons Island bulkhead had lower upland percent cover than the other two bulkheads (17%, 38%, and 55%, respectively).
The living shoreline structures were located on Little St. Simons Island (32.26014N -81.302W, permitting date 01/03/13, Figure 3.14) and Sapelo Island (31.43439N -81.28112W, permitting date 08/18/09, Figure 3.15 and Figure 3.16), Georgia. The Little St. Simons Island living shoreline was completed in 2013 and is made of bags of cleaned oyster shells stabilized with rebar stakes, a rock toe, geotextile lining the shoreline, and replanted vegetation. The western edge of the living shoreline structure abuts the previously existing bulkhead structure. Living shorelines have only been recently installed on the Georgia coast, and at the time of this study there were only three living shoreline structures in existence. The two used in this study were constructed of the most similar material (mesh bags of cleaned oyster shells installed on the shoreline with rebar stakes), while the third living shoreline was excluded because of its use of gabions. Due to the rarity of the living shoreline structures, it was necessary to use the structure that was immediately adjacent to the existing bulkhead structure on Little St. Simons Island. The Sapelo Island living shoreline was completed in 2010 and is made from mesh bags of cleaned oyster shells placed on the graded bank with rebar stakes to ensure placement. The habitat cover of the AOI plots are given in table 3.1. The two Sapelo Island sites are similar with regard to tidal creek percent cover (both 47%), and the Little St. Simon’s Island site and southern Sapelo Island site had higher upland percent cover rates than the northern Sapelo Island site (36%, 47%, and 14%, respectively).

**Vegetation Cover Analysis**

Only one side of each structure was sampled for vegetation due to ability of the researcher to access the area. Using a modified methodology from Hladik et al. (2014),
vegetation percent cover, type, stem height, and stem density (stem count/m²) data were collected at each site. Vegetation type was determined at each sample point, and vegetation percent cover was assessed using a 0.5 m² quadrat divided into 100 equal squares by fishing line. Each square in which any part of the vegetation fell was counted, and the total number of squares was the percent cover for the site. If a sample point fell on upland (non-marsh land), it was labeled as such. Vegetation type was documented for all sites, but percent cover was only documented for non-upland sites. All vegetation samples were collected between May and June of 2015 (Table 3.2) and utilized vegetation sampling methods from Currin et al. (2008).

Stem height and stem density measures were only collected from sample plots up to two meters from edge of the vegetation as it decreased to zero percent cover in the tidal creek, and the shoreline parallel transects this included were C, D, E, F, and G. The specific plots per site are given in table 3.3. Total stem height (where the stem emerged from the soil to the tip of the longest blade) of 10 haphazardly chosen stems that were within a 0.25 m² quadrats was measured using a meter stick (to the nearest cm). The stem density was calculated by counting all of the live and dead stems within the same 0.25 m² quadrat used for stem height measuring (Hladik, 2014).

To determine if the vegetation data were normally distributed, the percent cover, stem height, and stem density data were analyzed using the Shapiro-Wilk W test. To determine if the vegetation data had homogeneity of variance, the data were analyzed using Bartlett’s test. The data were found to be non-normally distributed without homogeneity of variance. Transformation of the data was avoided because of the small sample size so parametric analyses were deemed inappropriate. The vegetation
percent cover, stem height, and stem density measurements were ranked and the data were analyzed using a Kruskal-Wallis test to determine if there was any difference among the ranks of the different structure types for each vegetation parameter. Each structure comparison for each vegetation parameter was then analyzed post hoc using pairwise Wilcoxon Rank Sum tests with Bonferroni corrections.
RESULTS

There was a significant difference among the mean ranks of the structure types and controls with regard to percent cover (Kruskal-Wallis chi-squared= 16.274, df= 3, p-value= 0.0010). The post hoc analysis of the percent cover data showed significant differences between the riprap structure and all of the other sites (bulkheads, living shorelines, and control sites). The riprap structures had the lowest percent cover (71% (stdev± 28%)), and the bulkhead had the highest (98% (stdev± 3%)), although the control sites (97% (stdev± 9%)) and the living shoreline sites (94% (stdev± 11%)) were close in percent cover to the bulkhead sites (Table 3.5, Figure 3.24).

The results from comparing the stem height and stem density data among the structures show that there is a significant difference among the mean ranks of the groups for stem height (Kruskal-Wallis chi-squared= 21.207, df= 3, p-value< 0.0001) and also for stem density (Kruskal-Wallis chi-squared= 8.8625, df= 3, p-value= 0.03118). Post hoc comparisons for the stem heights show significant differences between the riprap and the control sites as well as between the riprap and the living shoreline sites. The means of the vegetation stem heights were lowest for riprap structures (42.00 cm (stdev± 16.64 cm)) and highest for the living shorelines (102.17 cm (stdev± 46.46 cm)) and the control sites (95.52 cm (stdev± 32.18), Table 3.5). The means of vegetation stem heights for bulkheads fell between the highest and the lowest values (74.70 cm (stdev± 35.21 cm), Table 3.5, Figure 3.25). Post hoc comparisons of stem density (stems/m²) show that there are no significant differences among any of the comparisons. However, the patterns shown by the means of the vegetation stem density data were lowest for the living shorelines (31 stems/m² (stdev± 16 stems/m²))
followed by the control sites (41 stems/0.25 m² (stdev± 24 stems/m²)). The riprap structures had the highest stem density (56 stems/m² (stdev± 28 stems/m²)) followed by the bulkheads (49 stems/m² (stdev± 20 stems/m²), Table 3.5, Figure 3.26).
DISCUSSION

One hypothesis for this project was that vegetation percent cover is lower adjacent to shoreline stabilization structures compared to erosional shorelines with no shoreline stabilization structure. The vegetation percent cover on the shorelines adjacent to the riprap structures was significantly different than the percent cover on the shorelines adjacent to the other two structure types or the control plots, with the vegetation percent cover lower adjacent to riprap structures (Table 3.5). The results of the current study partially support the hypothesis that there would be lower vegetation percent cover adjacent to shoreline stabilization structures. The three shoreline stabilization structure types in this study were different with regard to material and overall morphology: the bulkheads were vertical, relatively smooth structures and the riprap and living shoreline structures were graded and had texture. Patrick et al. (2016) found that in the polyhaline zone (salinity > 18 PSU), shoreline stabilization structures negatively impacted submerged aquatic vegetation because only small percentages of potential submerged aquatic vegetation habitat was occupied by the vegetation. Although the current study did not sample submerged aquatic vegetation, other studies have shown that shoreline stabilization structures can cause an increase of erosion on the shorelines immediately adjacent to the structure (Jackson, 2010; Mason et al., 2016), and this increase of erosion can alter the stability of the substrate which may result in a change in vegetation presence.

Another hypothesis for this project was vegetation stem heights and stem densities on shorelines adjacent to hard-armoring shoreline stabilization structures (bulkhead and riprap structures) are lower than those found adjacent to control sites.
This hypothesis was partially supported because there were significant differences among the vegetation stem height measurements between riprap structures and both the control sites and the living shoreline sites, but there were no significant differences among the vegetation stem densities for any of the comparisons. Riprap structures had the shortest overall stem heights as well as the highest stem density (Table 3.5). This shows an inverse relationship between stem height and stem density of *Spartina alterniflora* supported by previous research (Valiela et al., 1978). Valiela et al. (1978) studied the tall and short forms of *S. alterniflora* and found that the short form, which grows in the higher marsh, grows more densely than the tall form found in the low marsh immediately adjacent to the creek or river. Gleason et al. (1979) found that higher stem densities lead to more fallout of suspended sediments, which provided more space on which *S. alterniflora* could settle.

From qualitative observation, natural erosion exposes the established tall *S. alterniflora* of the low marsh adjacent to the tidal stream. The shorelines adjacent to the riprap structures have a distinct lack of an erosional scarp adjacent them when visited in the field, and they show a pattern of increased accretion and decreased erosion adjacent to the structures after installation (Tables 3.7 and 3.8). This possible addition of new substrate and subsequent new space for vegetation could account for the lower percent cover, lower stem height measurements, and higher stem density measurements. Shorter *S. alterniflora* stems grow more densely than their taller counterparts (Gleason et al., 1979), and in the case of the newly accreted substrates adjacent to the riprap structures, these stems may be younger. Although there may be more stems, the vegetation does not have extensive canopies and the measured
percent cover is less than that of the taller, possibly more mature *S. alterniflora* found on the eroding shorelines (Proffitt et al., 2003; Gallagher et al., 1988). These results suggest that riprap structures could be contributing to settlement of sediment, providing more tidal-creek-adjacent area on which new *S. alterniflora* can grow. However, due to the small sample size of this study, more research is needed to provide conclusive results.

The living shorelines show the same vegetation presence as the control sites when compared to the riprap structures. As the living shorelines show the same pattern of vegetation as the control sites, it is possible that the change rates of the shorelines adjacent to the living shoreline structures are not influenced by the installation of the structure. However, the pre- and post-installation shoreline change rates of the shorelines adjacent to the living shoreline structures have yet to be quantified in any of the states that have installed these types of structures (Myszewski and Alber, 2016). These shoreline change rates are necessary information to better understand how living shorelines compare to the shoreline stabilization structures already being used on erosive shorelines, and should be considered for further study.

The parameters for the success or failure of living shorelines have not been explicitly determined for the structures presently installed along the southeastern coast (Myszewski and Alber, 2016), but this study shows that the presence of vegetation on the shorelines adjacent to living shoreline structures is similar to that found on the natural, non-structured shorelines. Since the vegetation percent cover, stem height, and stem density do not differ significantly as what is found on the control sites, it is possible that the vegetation adjacent to the living shoreline structures is performing in
the same manner as the non-structured shoreline vegetation, maintaining integrity as an inland protection measure in the face of storm surge and sea level rise. Myszewski and Merryl (2016) suggest that the lower grade slopes of the living shoreline structures provide area on which vegetation may grow due to wave energy dissipation, thus these living shoreline structures could be better able to protect inland areas in the face of sea-level rise because they resemble stable, naturally occurring shorelines in grade and vegetation presence. Research conducted by Gittman et al. (2014) on the resilience of vegetation in the face of threats such as damage from hurricanes found that after Hurricane Irene, marsh vegetation stem density had decreased significantly in marshes with and without sills. Within a year, this marsh vegetation had recovered to pre-hurricane densities (Gittman et al., 2014). This is an important finding when considering the incorporation of vegetation into shoreline stabilization, such as with the living shorelines. If the vegetation percent cover and erosion rates on shorelines adjacent to shoreline stabilization structures are similar to those of natural shorelines not influenced by shoreline stabilization structures, then there is a likelihood that these shorelines will be more resilient in the face of sea level rise and inland protection.

These results support prior research stating that shoreline stabilization structures impact the biota of the shorelines on which they are installed. Lam et al. (2009) as well as Bulleri and Chapman (2004) found that there is a difference in the communities of epibiota (organisms than live on the surface of the substrate) on and around bulkhead structures compared to natural shorelines. However, there have been no significant differences reported for the biodiversity and abundance of organisms adjacent to riprap structures compared to natural, unstructured shorelines (Gittman et al., 2016). The
results from the current study support the idea that bulkheads may negatively impact the vegetation on adjacent shorelines, whereas riprap structures do not. The meta-analysis by Gittman et al. (2016) further states that data regarding the impact of shoreline stabilization structures, especially riprap structures, is lacking as they were only able to find a single study regarding the impact of riprap structures on adjacent vegetation. The current study provides much needed data regarding how stabilization structures affect vegetation on adjacent shorelines and how this compares to non-structured, natural shorelines. However, longer-term study of shoreline structure impacts, especially structure specific impacts, are still needed to provide better insight and management practices to coastal property owners and developers.
CONCLUSION

The purpose of this study was to determine the influence hard- and soft-armoring structures on the back-barrier shorelines of the Georgia coast. The effects of the different structures on the marsh shoreline vegetation were quantified, and the results of this study show that there is a significant difference in the vegetation presence adjacent to the different types of shoreline structures. Currently the riprap-structure-adjacent shorelines have differing percent vegetation cover and stem heights than the other structures, but the sample size needs to be increased for a more robust analysis. Although these data are not comprehensive, the results suggest that riprap structures and bulkheads should be considered as different structures with different influences on the adjacent vegetation. This differentiation will be critical moving forward in shoreline management because riprap structures may offer protection to adjacent shorelines whereas bulkheads may not. The living shorelines are only recently installed, and continued study of these structures is necessary to determine their long-term influence on shoreline change rates and the adjacent vegetation. The results of this study also provide initial methodologies and data for determining the influence of erosion control structures on back-barrier shorelines, and they provide a baseline for back-barrier shoreline stabilization structure study and the influence of each kind of structure on adjacent shoreline vegetation.
References


Georgia Department of Natural Resources. 2013. Living shorelines along the Georgia coast: a summary report of the first living shoreline projects in Georgia. Coastal Resources Division, Brunswick, Ga. 43 pp. plus appendix.


Karl Burgess at Ga DNR CRD- Personal Communication


### Tables

#### Table 3.1: Vegetation study site location information. This table includes the common name of the structure as designated in the GCSSPS, the county in which the structure is located, the conclusion date of the permit, and the structure type.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Type</th>
<th>Structure Length (m)</th>
<th>County</th>
<th>River/Creek</th>
<th>River/Creek Width (m)</th>
<th>Position</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Permit Date</th>
<th>% Upland</th>
<th>% Marsh</th>
<th>% Tidal Creek</th>
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**Table 3.2:** Vegetation sampling dates per site.

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</tr>
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<td>Sapelo Island Ashantilly Site North</td>
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<td>City of Savannah Bonaventure Cemetery</td>
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Table 3.3: Table of vegetation plots sampled within each area of interest plot. The plots sampled for vegetation height and stem density were within 2 meters of the termination of the vegetation.

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<td>Control Site 3</td>
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<td>G1, G2, G3, G4, G5</td>
</tr>
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</tr>
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<td>Little St. Simons Island- Berolzheimer Dock &amp; Fill</td>
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<td>UGA Marine Research institute</td>
<td>E1, E2, F3, E4, F5</td>
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<td>University of Georgia Skidaway institute of Oceanography (SKIO)</td>
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<td>Little St. Simons Island Living Shoreline</td>
<td>E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11</td>
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Table 3.4: The raw values for the vegetation percent cover, averaged stem height, and stem density analyses. These values were collected from sample plots that were within 2 meters of the edge of the vegetation as it decreased to zero percent cover in the tidal creek.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Habitat</th>
<th>% Cover</th>
<th>Average Stem Height (cm)</th>
<th>Stem Density (stems/m²)</th>
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<td>Stem Density (stems/m²)</td>
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</table>
Table 3.5: The average values and standard deviations for the vegetation percent cover, stem height, and stem count analyses. These values were collected from sample plots that were within 2 meters of the edge of the vegetation as it decreased to zero percent cover in the tidal creek.

<table>
<thead>
<tr>
<th>Structure</th>
<th>% Cover (stdev)</th>
<th>Average Stem Height (cm) (stdev)</th>
<th>Average Stem Count (stems/m²) (stdev)</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>96.89 (8.81)</td>
<td>95.52 (32.18)</td>
<td>40.6 (24.92)</td>
</tr>
<tr>
<td>Living Shoreline</td>
<td>94.44 (10.49)</td>
<td>102.17 (46.46)</td>
<td>31.33 (16.42)</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>98.38 (2.66)</td>
<td>74.70 (35.21)</td>
<td>49.23 (21.81)</td>
</tr>
<tr>
<td>Riprap Structure</td>
<td>70.83 (28.08)</td>
<td>42.00 (16.64)</td>
<td>56.33 (28.72)</td>
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</table>
Table 3.6: The p-values for the post-hoc Wilcoxon Rank Sum comparisons for the vegetation percent cover, stem height, and stem density analyses (control site n= 5; living shoreline site n= 2; bulkhead site n= 3; riprap structure site n= 3). The p-values reported have been corrected using the Bonferroni correction.

<table>
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<tr>
<th>Comparison</th>
<th>% Cover</th>
<th>Stem Height</th>
<th>Stem Density</th>
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<td>0.0018</td>
<td>0.0006</td>
<td>0.4932</td>
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<td>Riprap vs. Living Shoreline</td>
<td>0.0246</td>
<td>0.0006</td>
<td>0.0960</td>
</tr>
<tr>
<td>Riprap vs. Bulkhead</td>
<td>0.0180</td>
<td>0.1128</td>
<td>2.6718</td>
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<td>Living Shoreline vs. Control</td>
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<td>Living Shoreline vs. Bulkhead</td>
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<td>Control Vs. Bulkhead</td>
<td>4.1376</td>
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</table>
Table 3.7: The mean pre-installation end-point rates (m/yr) for shorelines immediately adjacent to hard-armoring shoreline stabilization structures in Georgia estuaries. The data presented in this table show that two out of the three riprap structures showed erosion before the installation of the structure while two out of the three bulkhead structures showed either no shoreline change or accretion before the installation of the structure.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Mean Pre-Installation EPR (m/yr)</th>
<th>Error</th>
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</thead>
<tbody>
<tr>
<td>Riprap</td>
<td>0.52</td>
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<td>Riprap</td>
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<td>Bulkhead</td>
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<td>0.00</td>
<td>0.21</td>
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<tr>
<td>Bulkhead</td>
<td>-0.23</td>
<td>0.12</td>
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</table>
Table 3.8: The mean post-installation end-point rates (m/yr) for shorelines immediately adjacent to hard-armoring shoreline stabilization structures in Georgia estuaries. The data presented in this table show that two out of the three riprap structures showed accretion after the installation of the structure while two out of the three bulkhead structures showed erosion after the installation of the structure.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Mean Post-Installation EPR (m/yr)</th>
<th>Error</th>
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</thead>
<tbody>
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<td>Riprap</td>
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<td>0.03</td>
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<tr>
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<td>-0.19</td>
<td>0.03</td>
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</tbody>
</table>
Figure 3.1: Diagram of the end-around effect. The original shoreline is denoted by the dashed brown line and the green line shows the shoreline as it is influenced by the end-around effect.
Figure 3.2: Salt marshes of Georgia. Shapefile courtesy of the U.S. Fish and Wildlife Service National Wetlands Inventory.
Fig. 3.3: Brayshaw and Lemckert (2014) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.

Fig. 1.4: Aerial view of the Tweed River entrance (a) showing the location of the training walls and sand pumping jetty (bottom left) and the jetty structure (b) (Source: NSW LPMA and QLD DERM 2011)
Fig. 3.4: Mason et al., (2016) in Pitfalls of Shoreline Stabilization. Used with permission of Springer.
Figure 3.5: Estuarine shoreline stabilization structures as designated by the Georgia Department of Natural Resources Coastal Resources Division. A) bulkhead at Plum Orchard on Cumberland Island, B) riprap structure on the coast of South Carolina, C) living shoreline on Little St. Simons Island.
Figure 3.6: Diagram of bulkhead with rock toe protection, courtesy of the U.S. Army Corps of Engineers.
Figure 3.7: The vegetation study site locations. Of the 13 sites there were 3 bulkhead, 3 riprap, 2 living shoreline, and 5 control sites.
Figure 3.8: Vegetation cover analysis site “City of Savannah Riprap” relative to the surrounding area (location: 32.048N -81.03944W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
**Figure 3.9:** Vegetation cover analysis site “City of Savannah-Bonaventure Cemetery” relative to the surrounding area (location: 32.04266N -81.04308W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013, and the habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3. This is a general representation of the area for reference purposes.
Figure 3.10: Vegetation cover analysis site “Jekyll Island Marina Boat Ramp” relative to the surrounding area (location: 31.04703N -81.42167W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.11: Vegetation cover analysis site “Little St. Simons Island Berolzheimer Dock Fill” relative to the surrounding area (location: 31.24856N -81.30444W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.12: Vegetation cover analysis site “UGA Marine Research Institute” relative to the surrounding area (location: 31.43611N -81.28055W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.13: Vegetation cover analysis site “UGA SkIO” relative to the surrounding area (location: 31.9854N -81.02265W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.14: Vegetation cover analysis site “Little St. Simons Island Living Shoreline” relative to the surrounding area (location: 32.26014N -81.302W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.15: Vegetation cover analysis site “Sapelo Living Shoreline North” relative to the surrounding area (location: 31.43439N -81.28112W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.16: Vegetation cover analysis site “Sapelo Living Shoreline South” relative to the surrounding area (location: 31.43439N -81.28112W). The structure delineation is provided by heads up digitization of Ga DNR CRD digital orthoimagery from 2013 and was verified through site visits. The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was also verified through site visits. This is a general representation of the area for reference purposes.
**Figure 3.17:** Progression of shoreline preparation for analysis: A) delineated shoreline stabilization structure (blue line), B) straight line between the endpoints of the structure (pink line), C) relative placement of polygons (orange rectangles) perpendicular to the structure endpoint line, D) heads-up digitization of shorelines that fall within the polygons (green line- year 1 shoreline, red line- year 2 shoreline).
Figure 3.18: Vegetation transect and sampling plot layout. The blue line is representative of the structure, and the pink line represents the 50m transect cast from immediately adjacent to the structure along the observed shoreline. The perpendicular transect numbers begin with 1, which is immediately adjacent to the structure.
Figure 3.19: Vegetation cover analysis “control site 1” relative to the surrounding area (location: 31.241436N -81.304214W). The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3. This is a general representation of the area for reference purposes.
Figure 3.20: Vegetation cover analysis “control site 2” relative to the surrounding area (location: 31.242053N -81.304069W). The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3. This is a general representation of the area for reference purposes.
Figure 3.21: Vegetation cover analysis “control site 3” relative to the surrounding area (location: 31.242514N -81.303324W). The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3. This is a general representation of the area for reference purposes.
Figure 3.22: Vegetation cover analysis “control site 4” relative to the surrounding area (location: 31.243864N -81.302586W). The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3. This is a general representation of the area for reference purposes.
Figure 3.23: Vegetation cover analysis “control site 5” relative to the surrounding area (location: 31.257683N -81.301544). The habitat delineation is provided by digitizing the basemap imagery in ArcGIS 10.3 and was verified through site visits. This is a general representation of the area for reference purposes.
Figure 3.24: The average vegetation percent cover adjacent to the structures and the control sites with standard deviations. (control site average = 96.89, n = 5; living shoreline site average = 94.44, n = 2; bulkhead site average = 98.38, n = 3; riprap structure site average = 70.83, n = 3).
Figure 3.25: The average vegetation stem heights adjacent to the structures and the control sites with standard deviations. (control site average = 95.52 (stdev = 32.18), n= 5; living shoreline site average = 102.17 (stdev = 46.46), n= 2; bulkhead site average = 74.70 (stdev = 35.21), n= 3; riprap structure site average = 42.00 (stdev = 16.64), n= 3).
Figure 3.26: The average vegetation stem count per plot adjacent to the structures and the control sites with standard deviations. (scaled up from 0.25 m$^2$ to 1 m$^2$ control site: average= 40.6, n= 5; living shoreline site average= 31.33, n= 2; bulkhead site average= 49.23, n= 3; riprap structure site average= 56.33, n= 3).
CHAPTER 4

Conclusion

This project was intended to show the potential impacts on shoreline change with regard to the installation of shoreline stabilization structures and the subsequent influence on vegetation. Research so far has utilized remote sensing data on a large timescale, and this project focused on a smaller geographical scale within the same timeframe as well as incorporating field vegetation sampling methods. These results are needed to better understand the direct influence erosion prevention measures have on the adjacent non-armored shorelines. The shoreline change rate analyses suggest that the shorelines adjacent to riprap structures may be experiencing less erosion than those adjacent to bulkheads, and may even be experiencing accretion at some individual sites. These results also show that the shorelines adjacent to these hard-armoring structures are disturbed by an end-around effect on an individual basis, but the sample size is too small to make overall assumptions of the influence of the structures. The vegetation analysis shows that presently, the shorelines adjacent to the living shoreline structures are the most similar to the non-structured control sites with regard to vegetation cover and those adjacent to riprap structures have lower percent cover and higher stem densities, supporting the difference seen in the shoreline change rate analyses.

Chapter 2 showed that shoreline change rates did not differ among the shorelines on which structures were built. However, the shoreline change rates adjacent to bulkhead structures were overall more erosional (had a more negative end
point rate of change) that the rates adjacent to the riprap structure shorelines. The end-around effect pattern was present in all but one of the riprap structure sites, and it was present in all but two of the bulkhead sites. These results show that on an individual level, the installation of a shoreline stabilization structure will influence the rates of change of the shorelines immediately adjacent to them. Bulkheads are known to promote the loss of beach on oceanfront shorelines and influence the sediment dynamics of the immediate area, so the results from this study support the assumptions held that shoreline stabilization structures in the back barrier estuary have similar effects on shorelines as beachfront stabilization structures (Nordstrom, 2014).

The vegetation study of Chapter 3 shows a significant difference in vegetation cover on shorelines adjacent to shoreline stabilization structures relative to non-structured, erosive shorelines. An inverse relationship between stem height and stem count was shown in the vegetation cover adjacent to the hard-armoring structures compared to the soft armoring shoreline stabilization structures and the non-structured shorelines: as the vegetation stem height increases, the overall number of stems in the same space decrease. The presence of vegetation on estuarine shorelines is critical to shoreline stabilization as the vegetation stems slow the water velocity as it flows over the area, allowing for the sediment to fall out of suspension and ultimately sustain and possibly build up the shoreline.

Better understanding the influence of shoreline stabilization structures is important as more of the back-barrier shorelines are being developed and stabilized. Although the structures used on the back-barrier shorelines are one of three types (bulkhead, riprap structure, or living shoreline) each shoreline stabilization structure is
unique and overall patterns are difficult to discern. There is a new argument of whether soft-armoring structures (living shorelines) are a better alternative to shoreline stabilization than the hard-armoring structures that have been used for decades, and this project not only sets the groundwork for future study comparing the living shorelines to the hard-armoring structures, it also proves a methodology that can be used for this future study, as well as failings in this methodology and the data sets used.

As research advances and the need for accurate shoreline change rate data increases, the influence of anthropogenic activities and erosion control devices cannot be ignored. Coastal populations continue to increase, and this necessitates the proper management and conservation of ecologically and economically important areas. Current and future researchers and managers now have a baseline for shoreline change rate data with regard to hard-armoring shoreline stabilization structures in the back-barrier of Georgia. They can use these data so corrections can be made to the pre-existing shoreline change rate data. The now-quantified effects of these hard-armoring structures provide another link between the utilization of coastal areas and anthropogenic influence on these areas. Shoreline change, sea level rise, and storm surge protection are all topics for which these data can be used to determine the vulnerability of coastal development and habitats either by allowing shorelines to be artificially stabilized or left unhindered.