“THE RISING EDGE: ADAPTING SAVANNAH TO THE EVER-CHANGING COAST”

by

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(Under the Direction of Brian Orland)

ABSTRACT

With sea level rising and climate change creating more frequent “super storms”, resiliency is vital in the protection of the coastline. This thesis examines the use of native trees, shrubs and grasses implemented as mainland, inland, coastline and wetland ecological systems in coastal Georgia to increase the resiliency of the community to coastal erosion, sea level rise, storm surge and storm-related wind damage. Responding to new information on coastal residents' attitudes and intended behaviors with respect to climate-related change, this thesis will present considerations for design best management practices that are applicable to residential landscapes in Savannah, Georgia

INDEX WORDS: Storm Surge, Climate Change, Salt Tolerant Plants, Super Storms, Hurricane, Resiliency, Landscape Architecture

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DEDICATION

This thesis is dedicated to my incredible family and friends. Without their endless amount of support, love and patience, I would not have been able to reach this point and achieve my goals.

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CHAPTER 1

INTRODUCTION

In Colonial America, agriculture and the coast were the primary livelihoods for most of the population. The great majority of farms were subsistence, producing food for the family and some for trade and taxes. The first settlers planted barley and peas from England, but their most important crop was corn, which they were shown how to cultivate by Native Americans. Farmers supplemented their income with sales of surplus crops in the local market, or by coastal exports.

After some time, and as the country grew in size and population, plantation agriculture (e.g. tobacco, rice, cotton, sugar), using slaves, developed in the Southern United States. Then, largely due to the Industrial Revolution in the late 18th and early 19th centuries, the United States experienced rapid industrialization and the rise of cities. Cities served as centers of storage, distribution, trade, and manufacturing. Many of these cities were built and developed proximal to waterways (rivers, streams, oceans) in order to provide for the community and also to function as natural harbors for commerce, trade, and transportation.

New York City, New Orleans, and Savannah are examples of major cities that rapidly developed during the United States' Industrial Revolution and the urbanization it brought along. Populations grew very quickly; for example, New York had a population of about 313,000 by the mid 1800's but it ultimately reached roughly 4.7 million in 1910 (Ellis 2016). Millions of rural Americans no longer needed on farms flocked to the cities, where opportunities for jobs (as new factories adapted to new markets) and better living conditions were expanding. In addition, millions of immigrants from Europe increased urban populations. More and more, urban economies were integrated with the national and international economies, and the cities grew over the next century to reflect that.

The newly arriving urban immigrants settled in less desirable, peripheral and low-lying land, because the best land had already been taken or was expensive. Their poorer economic situations caused them to build with less concern for durability and resilience, or to find accommodation to rent from landlords also investing the minimum in their properties. As a result, a growing population of more vulnerable people gravitated toward living on the most vulnerable land.

Today, cities continue to grow in population and size. Not only in the United States, but globally, the world is experiencing an even more dramatic shift to urban living than during the industrial Revolution. In 1900, 10% of the global population were urban dwellers, but now it is more than 50%. Also, individual cities are growing to unprecedented sizes, with many cities housing over 10 million people (Madhani 2016). There is a growing lack of opportunities in rural settings, so people are moving to urban centers, where they perceive more opportunity. However, more and more the explosion of cities is providing its own set of problems.

Problem:

Although city populations are slowing compared to past centuries, the population is still growing. Today, the edges of cities are expanding into surrounding rural landscapes, causing changes in soils, plants, animal ecosystems, and built structures. The concentration of transportation and industry in urban centers means that cities are major sources of CO_2 and other greenhouse gases. This affects Earth's climate negatively, leading to more problems. Sea level rise and frequent super storms are examples of issues that have arisen or been exacerbated by man-driven climate change. According to the Environmental Protection Agency's Climate Change Indicator, sea levels on the East coast of the United States have risen by 4-8 inches.

Since 1993, it has risen 0.11-0.14 inches annually, which is twice as much as recorded for previous years (NOAA 2012). Sea level rise, propelled by human-driven climate change, is the main cause of coastal tidal flooding issues. On average, coastal areas experience 24 tidal floods, however, as sea level rises, coastal communities are expected to see a triple in average tidal floods by 2045 (Union of Concerned Scientists 2014)

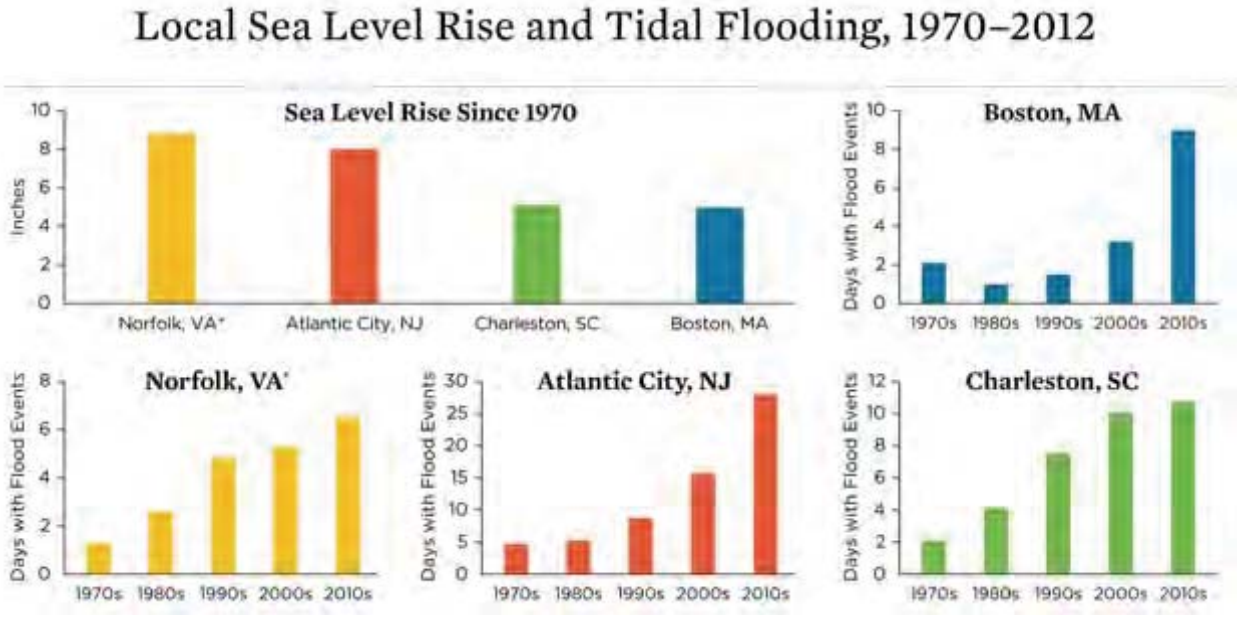


Figure 1. Example of Local Sea Level Rise and Tidal Flooding, 1970-2012 (Boston, MA; Atlantic City, NJ; Norfolk, VA; Charleston, SC) (Union of Concerned Scientists, 2014)

Though the numbers appear small, the lasting effects that sea level rise has on coastal communities are large and enduring. Super storms are defined as a "severe and widespread storm characterized by record-setting meteorological events and large-scale destruction", which is seen most recently with Hurricane Sandy (formally known as Superstorm Sandy), the Bering Sea Cyclone. The changes of the Earth's climate have resulted in severe changes that impact everyday life.

Sea level rise and super storms can cause unprecedented damage. Furthermore, the disproportionate location of cities along rivers and coastlines makes these areas important contributors coastline erosion. Clearly, cities were not originally built, nor updated in the recent past, to withstand modern day problems.

Savannah, Georgia is one such city currently facing the environmental and economic issues that accompany climate change. With Savannah's proximity to the coast, it seems that it is only a matter of time before sea level rise or a catastrophic super storm destroys the historic city. Sea level rise is already causing major destruction to the coastline and testing the current methods of dealing with storm surge. Urban developers are not systematically replenishing natural wetlands, marshes, and coastlines with salt-tolerant plants, which has the effect of eroding the barriers that would prevent storm surge from inundating new areas even higher than before. Furthermore, the energy from warmer coastal waters is causing storms to become stronger and more frequent. Together these present immense potential impacts for people and structures.

However, Savannah has the opportunity to change and cultivate land uses and design practices that are more climate change-resilient. To be expected, most residents of Savannah are not willing to relocate. There is enormous cultural attachment to the city, of course, as well as to the families, friends and, simply, to home. However, most people lack any substantial understanding about the likely immediate effects of climate change on their surroundings, nor any measures that they could take to reduce or resist any dangers. Urban resiliency to climate change is now an issue at the forefront of redeveloping and protecting areas prone to environmental and economic disaster.

Solution:

It is important that designers begin talking about what actions need to be taken to ensure the protection of cities like Savannah. The reintroduction of salt tolerant plants on beaches, in parks, in neighborhoods, apartment complexes, duplexes and even on the individual home scale would slow the rate and extent of water intrusion and inundation during major storms. This form of fortification for sites ranging from inland to waterfront would be relatively easy to implement and will reduce the damage that occurs during human-driven climate change and environmental disasters. Choice of landscape materials, both hard and soft, that can tolerate inundation, salt damage and wind damage would allow places to “return to normal” more quickly and thus contribute to restoring “sense of place”.

CHAPTER 2

LITERATURE REVIEW

Sea Level Rise:

Sea level rise has caused major damage to the coastline and is testing the current methods in place to deal with storm surge. Many of the barrier islands off the coast of Savannah have significantly eroded due to rising sea level and consequently, salt-intolerant vegetation is unprotected from seawater (Henry 2015). Consequently, the vegetation dies, and storm surge is allowed to inundate even higher than before (Pisaric et al. 2011). Recently, however, some urban developers, landscape architects, environmentalists, and sociologists have begun to publish ideas for systematically replenishing natural wetlands, marshes, and coastline with salt-tolerant plants, consequently reducing the risk of environmental, social, and economic damage to coastal cities.

Environmental damage for which coastal cities are at risk is perhaps most emphasized in literature. In recent decades, it has become evident that human-driven climate change is occurring at a rate of approximately 10 times faster than what was previously expected to occur (NASA 2017a) The global climate crisis is propelled by consequences of human activity, including the surge of atmospheric CO_2 levels through industry and deforestation of countless acres of land across the world. This surge has led to the melting of the polar ice caps, and the warming of the oceans (NASA 2017b). As the oceans warm, they also expand in size due to laws of thermal expansion.

The oceans are absorbing more than 90 percent of the increased atmospheric heat associated with emissions from human activity (NOAA 2015). The two major causes of global sea level rise are thermal expansion caused by warming of the ocean and increased melting of land-based ice, such as glaciers and ice sheets. Thus, the most apparent consequence of higher

water temperatures is a rise in sea level. Scientists have determined that global sea level has been steadily rising since 1900 at a rate of at least 0.04 to 0.1 inches per year (NOAA 2015). Sea level rise causes inundation of coastal habitats, displacement of humans and animals, shoreline erosion, and more powerful storm surges that can devastate areas at low elevation.

According to the Environmental Protection Agency's (EPA) climate change indicator for coastal flooding, throughout the past 2000 years, there was little change in global average sea level. However, since the industrial revolution, the rate of change has dramatically accelerated. Since 1993, average sea level has risen at a rate of 0.11 to 0.14 inches per year – twice as fast as predicted (NASA 2017).

According to the same EPA climate change indicator, sea levels on the East coast of the United States in particular have risen sharply in recent years (NASA 2017). The Mid-Atlantic coast and parts of the Gulf coast saw sea level increases of more than 8 inches in the past 50 years (Titus et al. 2009). From 1880 to 1990, sea level rose 0.06 inches annually on average but since 1993, it has risen 0.11-0.14 inches annually. Though the numbers appear small, the lasting effects that sea level rise has on coastal communities are large and enduring (NASA 2017).

It is estimated that within the next 15 years, global sea levels will continue to warm and will likely rise another six inches (Goodell 2017).

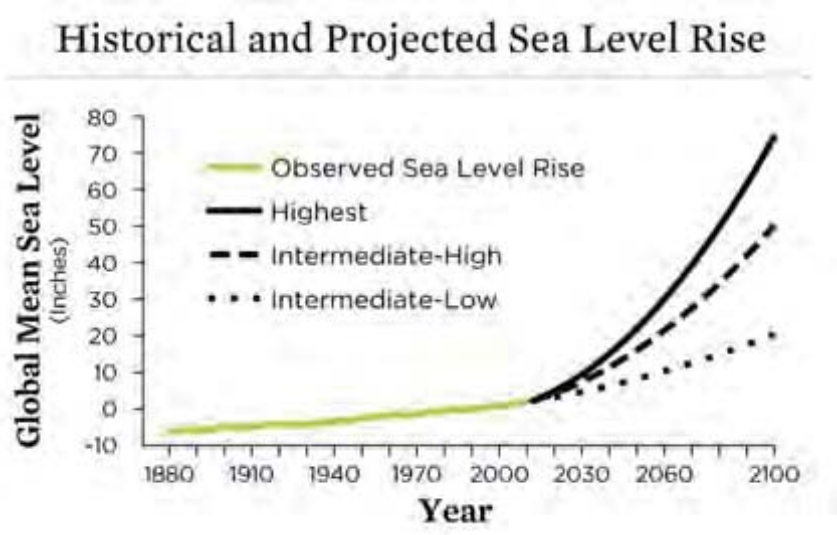


Figure 2. Historical and Projected Sea Level Rise (Global Average) (Climate Change N.D.; Walsh et al. 2014)

Besides thermal expansion, another consequence of warm oceans is that storms become more powerful, ultimately causing significantly more environmental damage through flooding, storm surge, and the intensification of normal environmental phenomena. The environmental effects of a natural phenomenon called “blue-sky flooding” are worsening with increasing sea level rise. According to NOAA, “blue-sky flooding” is an occurrence that involves extreme high and low tides in a short period of time (Harrington 2017). Blue-sky flooding events, known colloquially as “king tides”, are partly dependent on the gravitational pull from the moon; however, their frequency and intensities are increasing substantially. The Barrier Islands off the coast of Georgia, which physically protect the coast from wave action, have becomes more at risk for blue-sky flooding consequences within the last decade (Harrington 2017) Sapelo Island, in particular, is facing new harsh conditions. According to NOAA (NOAA 2017) floods from

blue-sky tides used to occur only five times per year. However, according to Adam Mackinnon, a scientist and researcher on Sapelo Island, floods are now occurring 30 to 40 times a year (Harrington 2017).

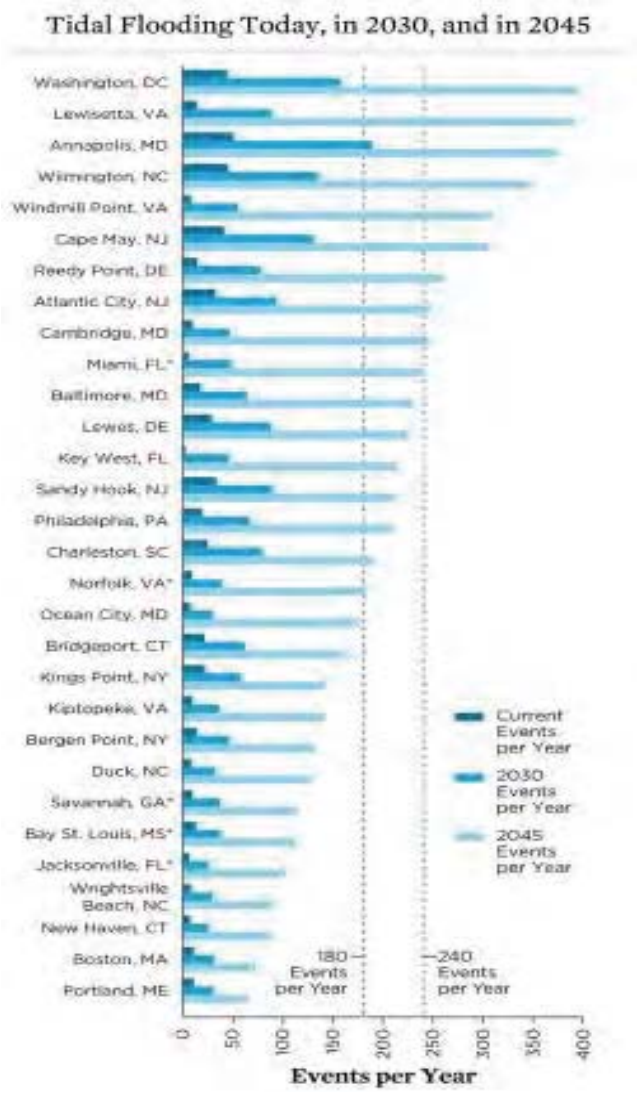


Figure 3. Tidal Flooding Today, in 2030, and in 2045 (Union of Concerned Scientists 2014)

Floods, which erode coastlines and inundate soil and plants, is “wreaking havoc” on Sapelo Island’s forest (Harrington 2017). Inundation and warm water has created an opportunity

for foreign insects to make the island their home. Sapelo Island has lost thousands of acres of forest land due to the spike in non-native pine beetles (Harrington 2017), which migrate to the warmer climate the southeast increasingly provides. Sapelo Island is 72 miles south of Savannah and, because Savannah is a coastal city, their vulnerabilities to climate change are almost identical. Coastal cities further north face the same risks of frequent flooding attributed to sea level rise and storm surge (Kemp et al. 2013). The northeast coast of the U.S. tends to be more prone than the mid-Atlantic to hurricanes. Tidal variations are normal during hurricanes but have become exaggerated with the increasing of storm severity over time. These tides, partially driven by high-force hurricane winds, lead to higher and longer-lasting floods inundating ecosystems. Damage to ecosystems by habitat destruction, introduction of non-native species, or direct killing of plant and animal life ultimately contributes to a decline in biodiversity, stability, and environmental resiliency.

Storm Frequency and Severity:

Natural ecosystems are not the only aspects of coastal regions being affected by human-driven climate change. The effects of climate change have dire social and economic consequences also. Hurricanes and super storms cause billions of dollars in damages. This past year, the southeast of the United States was hit with 17 named storms and was listed in the top 5 most-active hurricane seasons since 1851 (Drye 2017). The U.S.'s reliance on waterways for transportation of goods has increased since the Industrial Revolution and continues to as it increasingly becomes more of a nation reliant on imports and exports. For generations, populations have been migrating to the coastlines for work and access. Urban development in recent decades has become unprecedented. Cities such as New York, Miami, New Orleans, and Savannah have increased the size of their ports, the amount of goods export, and the size of their

"grey" infrastructures. As an island, New York City has almost maxed out its capacity for built environments. The over-population in 2016, New York City had an estimated population of 8.5 million people, (US Census 2016) and lack of coastal defense puts residents and business at imminent risk for damage due to super storms. Unfortunately, as the risk of damage increases, scientists' ability to predict their timing and severity decreases (Shullman and Lin 2017).

In 2012, New York and New Jersey faced one of the most devastating hurricanes of the 21st century. Hurricane Sandy hit northeast coast, which historically has not faced many super storms, with devastating power. The coastal infrastructures of New York and New Jersey had not been designed to withstand the conditions Sandy brought with an average of 9' storm surge, the water levels crashed into the subway systems, buildings, and homes of these coastal residents (Goodell 2017). The damage that occurred was predominantly from flooding. In Staten Island, a borough of New York City, an unprecedented amount of water rushed on to the 22-square mile island. The storm surged flooded the 9/11 Memorial, the subway systems and thousands of business and apartments (Kemp et al. 2013). When New York City was hit by the super storm, it made landfall during high tide and during a full moon (Kobilka 2017). This caused storm surge to rise to 14 feet, which flooded Battery Park in the south of Manhattan. Estimated at $32 billion in total damage, it was the second costliest hurricane in United States history until 2017 (Kemp et al. 2013). In neighboring New Jersey, more than 80% of Atlantic City was inundated during the storm (Amadeo 2008). According to research, the New York City Panel on Climate Change, (NPCC) claims that by the year 2025, the water that surrounds the New York metropolitan area, Long Island and New Jersey will rise 10 inches. Miami is another city at very high risk for social and economic damage due to climate change. On average, Miami is only 6' above sea level, but during blue-sky events, which occur roughly twice a month, tides rise by 3', bringing water

inland (Goodell 2017). Therefore, unless no measures are taken, Miami can be expected to be under water by 2030 if sea level continues to rise (Goodell 2017). Similarly, it is estimated that by 2050, and with a 3’ sea level rise, Tampa will have to spend $300-$900 billion dollars to rebuild its real estate market. According to the U.S. Census, Florida experienced an 8% increase in population along the coasts in 2015 as opposed to the early 1990’s (Ruggeri 2017). Expansion of and migration to Florida’s beachfront means that more people and structures are susceptible to damage during storms.

CHAPTER 3
SUSCEPTIBILITY OF COASTAL GEORGIA

Savannah is facing higher climate change-driven social and economic risks as well. Like the other cities, Savannah is built on water: to the east is the Atlantic Ocean, and to the north is the Savannah River.

Figure 4. Chatham County Context Map (ArcGIS and SAGIS) (2018)

This active access point allows residents and visitors from around the world to experience Savannah's rich history, its waterfront restaurants and shops, and beaches. Migration to Savannah in recent years has increased. However, with development increasing in coastal cities around the United States, rising sea level is increasingly threatening the integrity of the coastline and its communities. The residents of eastern Savannah, and specifically the barrier islands (Tybee, Wilmington, Skidaway, etc.) are experiencing severe flooding on a more regular basis (Carter 2015). The islands are also facing erosion on the south end of the islands, which can be attributed to sea level rise.

Figure 5. Example of Aftermath Hurricane Irma Flooding – Tybee Island, GA (Ethridge 2017)

Many coastal cities like Savannah are protected by seawalls and jetties; however, these infrastructures are compromised during super storms, as in the case of New Orleans and Hurricane Katrina (Carter et al. 2015), which produced unparalleled storm surge reaching 20'. This storm surge did not recede for six weeks (Zimmermann 2015).

During Hurricane Matthew in 2016, the urban center of Savannah –home to thousands of residents as well as local and chain businesses– was flooded. Off the coast, a large portion of

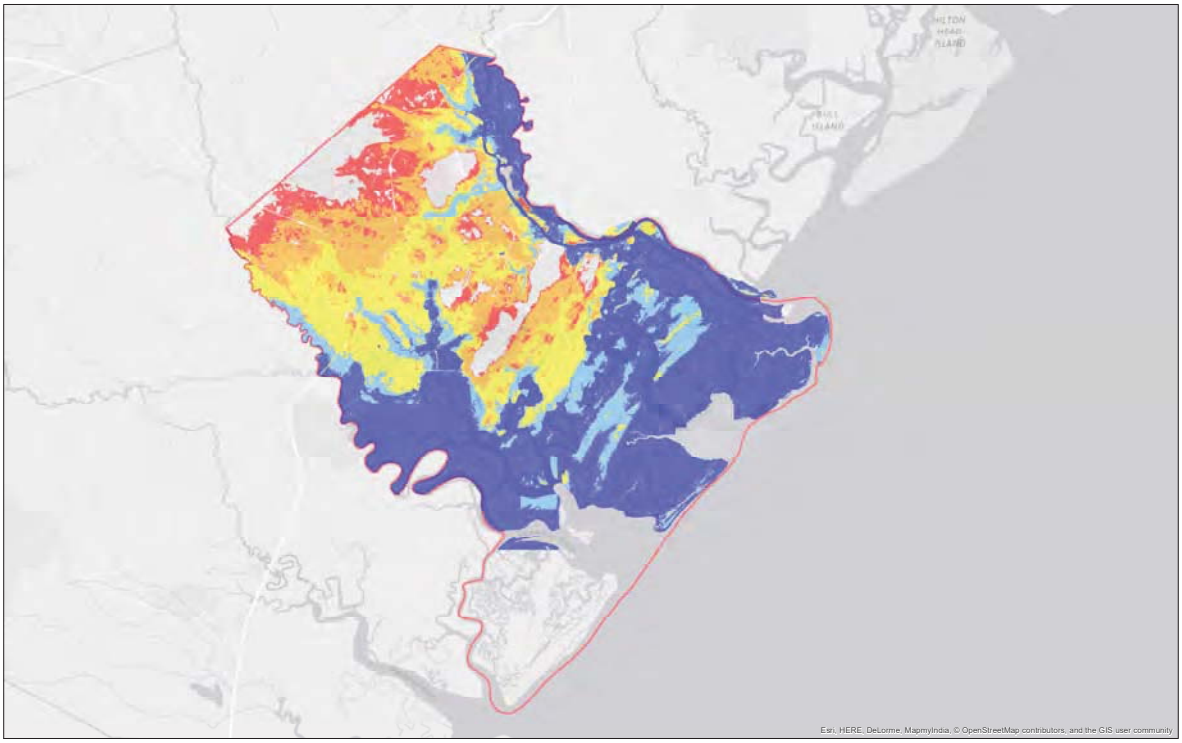


Figure 6. Chatham County Storm Surge Zones (Categories 1-5) Scale 1:24,000, Georgia GIS Clearinghouse (2008)

low-lying Tybee Island was also under water. During hurricanes and king tides, roadways are susceptible to inundation to a point resident cannot pass through. U.S. Highway 80 is the only route connecting Tybee to mainland Georgia but most of it was inaccessible during and after the hurricane because of flooding. This made it impossible for residents of Tybee Island to evacuate their homes to safety (Georgia Clearinghouse GIS Map 2017).

Homes and businesses on Tybee Island sustained significant structural damage from floods and trees taken down by high-force winds (interview conducted by Meredith Welch-Devine). Less than a year later, Savannah was hit by Hurricane Irma and similar devastation ensued. (Shullman and Lin 2017). In this instance, as in many others, the amount of damage

produced during the hurricane are unknown until the cleanup process begins. Therefore, it is essential to analyze the dynamic effects sea level rise and storm surge bring (Shullman and Lin 2017). The river on which Savannah is built is currently undergoing a mass engineering expansion. The plans, to be completed in 2022, are set to dredge the river's bottom from 42 feet deep to 47 feet. This will cost an estimated $973 million dollars (Hutchins 2017). This project will spread over 41 miles inland and increase the rivers ability to withstand large cargo ships. However, another consequence of this dredge will be the volume of water held by the river. This will ultimately lead to more severe flooding and long-term inundation during storm surges and king tides.

Shoreline Protection:

Given the extensive environmental, social, and economic risks climate change poses to coastal cities, what measures have been taken to combat them? In the past, landscape architects, city planners, designers, and engineers have implemented the use of seawalls and bulkheads as the main means to protect coastlines This is the case in North Carolina, South Carolina, Florida and Georgia. Traditionally thought as the most resilient and applicable design technique, seawalls and bulkheads prevent erosion and slow the rate of flooding during storms; however, as seen in North Carolina after Hurricane Irene in 2011, 93% of shoreline damage was attributed to bulkhead and seawall damage (Smith et al. 2017). However, the use of bulkheads is very costly (Smith et al. 2017) and, with the increasing number and severity of storms and hurricanes, their longevity is compromised. Historically, cities, states, and the Army Corps of Engineers have set aside aid to rebuild man-made seawalls, levees, jetties, dikes, etc. in the case that they are compromised. During Hurricane Katrina, the levees that protected New Orleans were compromised. This ultimately resulted in the heavy death toll, as well as a long and heavy storm

surge. To rebuild the levee structures cost $9.5 billion (Whoriskey and Hsu 2006). If enough of these rebuilding projects occur successively, the U.S. could experience and economic downturn. Because the rate of sea level rise due to climate change is accelerating, management practice must adapt.

Savannah in particular is a city that could benefit from a more easily adaptable protection scheme. After Hurricane Matthew, Savannah experienced severe inundation and erosion, which is credited to the lack of protection on the barrier islands and flooding of the Savannah River. Savannah has a historic downtown filled with outdated, grey infrastructure. While engineering solutions can offer temporary fixes, it seems that man-made coastal protection structures are no longer the best management practice for Savannah. More effective would be nature-based coastal protection (Zimmermann 2015). Although a different solution could possibly better serve over-developed areas, the areas that face the seaside and have undergone severe erosion could benefit from natural coastal restoration. In theory, this benefits ecosystems, prevents further erosion, slows the rate of inundation during storm surge, and saves Savannah from social and economic disaster.

Building coastal resiliency for areas that are likely to be affected by climate change and rising sea level is regarded as a key environmental concern (Cunniff 2016). The health of the ecosystems that comes into increasingly frequent contact with sea water is diminished because this shortens the lifespans of plants species which have not evolved to tolerate high salinity levels. These degraded ecosystems require replenishing restoration work to maintain the health and the vitality. Ecological restoration of damaged areas can contribute to healthy biodiversity, stability, and resiliency. They create habitats for wildlife, and food and protein sources that support biodiversity. They usually require less maintenance for establishment. Long term, they

can combat climate change because long-living native plants can store more CO_2, which helps minimize levels in the atmosphere. Native plants also use less water because they are adapted to local conditions (Audubon Society 2017). In the past two to three decades, the importance of healthy ecosystems and ecological restoration have been integrated into landscape architecture in order to tackle the challenges climate change and frequent super storms generate (Stefanes et al. 2016).

Though scientists and land managers recommend using local ecotypes for restoration projects, there is not a scientific consensus on what constitutes "local." To gain information about production and use of locally sourced plant material, a research team recently interviewed conservation professionals and nursery professionals, to learn if there were differences between these groups in terms of their use, sale, or perception of “native” and “local” ecotypes (Altrichter, Thompson, Mabry 2017). Their survey results indicated that both groups are aware of the ecological and functional value of native plant communities; however, nursery professionals provide less local ecotype and source-certified plant material in their businesses than the conservation professionals think is appropriate. Though, conservation professionals indicated that their organizations did not have guidelines for sourcing local ecotypes. Although nursery professionals are aware of restoration techniques and the usefulness of local ecotypes, this does not appear to influence how much of these ecotypes they produce for sale (Altrichter, Thompson, Mabry 2017). Clearly, there needs to be more communication and a better spread of information.

Another aspect in which information is still needed is in the distribution and character of nearshore and inner continental shelf sand. The aim of one recent study was to establish where sands compatible with Georgian islands (Sapelo Island, St. Simons and Jekyll Islands) lie in the

case that they are needed to rebuild beaches after significant storms to protect infrastructure and to restore habitat (Clark 2016). Sand resource data for Georgia is the most poorly known of all the states along the East Coast. The Bureau of Ocean Energy Management (BOEM) and the NOAA Sea Grant Program are funding the efforts to collect this data.

There are some key issues, however, hindering the healthy restoration of coastal cities like Savannah. Ecological degradation is a global problem. And different countries have taken different actions as part of their restoration initiatives. However, there is still a lack of methodological strategy to assess and prioritize existing technologies. One recent study has proposed a three-phase method (TheMert 2016) for evaluating the most appropriate restoration technologies for the problems at hand. The focus of this study was commercial spaces and protecting public areas from rising sea level. This goal of this study was also to increase the awareness of policy makers and the public on the role of technology in restoring degraded ecosystems. However, another key issue hindering efficient restoration is the public lack of understanding of the importance of reestablishing native, salt tolerant plants. According to research conducted after Hurricane Sandy, 43 people died, 90,000 buildings were flooded, and there was $19 billion in damage in New York and New Jersey. Historical cities face the most damage because of outdated infrastructures; however, historical cities are often bigger and offer more opportunity, and so they attract migration. Despite increasingly high risks of storm damage and loss of life, migration to historical coastal cities continues. With migration comes increased industrial and private development on the coastlines. It is difficult and impractical to convince those that have called Savannah home for generations to consider safer areas. Similarly, those that recently moved to Savannah and have yet to experience the effects of frequent storm often

do not see climate change as an immediate threat. This can be devastating if measures are not taken to protect these communities.

Another hindrance is funding. When surveys were conducted in 2017, it was found that a more “nature-based” coastline was, in the long run, more financially effective and resistant to physical vulnerability (Smith et al. 2017). However, this is often not perceived as true by decision makers. Often, only funding for short-term solutions like seawalls and jetties is available for storm defense, and decisions are made without considering the long-term benefits of reestablishing natural ecosystems. These barrier systems are also ineffective for some aspects of climate change. For example, the barriers are supposed to remain open until a storm arises and increases wave height. They can be closed full-time, but this doesn’t mitigate the effects of sea level rise.

The global climate crisis is an existential threat. The impacts do and will affect everyday life. The health of ecosystems is diminishing, sea level is rising, and storms are becoming stronger. Savannah, Georgia, a historic city that thrives on the coastal lifestyle is facing the reality of climate change. Historically, the residents of Savannah have built and rebuilt after hurricanes, but now, with dire predictions for the future of the climate, a resilient plan must be put in place. Many engineers, environmentalists, ecologists agree that a natural, native boundary is needed to rebuild the resiliency of Savannah. This thesis is innovative because it suggests reestablishing native, salt tolerant plants in strategic areas that are most prone to erosion and flooding to slow rates of flooding and inundation. For the purpose of this thesis, the focus was on the native coastal plant materials for their characteristics of salt tolerance, wind resistance and natural resiliency. Native plants, which are defined as “a population of plants within a defined geographic area that exist there without direct or indirect human introduction.” (Waitt 2007)

were crossed-referenced by experts for their efficiency in protecting the coast. Though exotic plants are often considered more aesthetically pleasing, city planners and private residents need to take the global picture into account when designing outdoor areas. However, all of the plants in this thesis are adapted to conditions of coastal plains. Because of this, most of them have the ability to withstand very moist soil with high salinity, and to form deep roots for soil integrity. They are less likely to dehydrate in the presence of salt water and are therefore, less likely to be damaged during storms. The designs are ambitious but practical in the face of our changing climate.

CHAPTER 4
METHODOLOGY

In Savannah, the locations designed for were: Coastal, Marshland, Inland and Mainland. Although Savannah is a relatively flat area of Chatham County, the elevations range within the property lines, including areas of small “hills” in which large quantities of storm runoff is produced. Savannah received over 48 inches of rainfall last year, and had more than 4 major flash floods, including the storm surge from Hurricane Irma. Because of this, the designs required areas of dense plantings to slow the rate of storm runoff.

Also, in parts of Chatham county, the average elevation is 49’ above sea level and on Tybee Island, it is an average of 10’ above sea level. Although these areas are averages, there are also low elevations points within the community, dropping down to 2’ above sea level in certain parts of Wilmington Island (SAGIS 2018).

Savannah is prone to the issues associated with climate change because of the proximity to the Atlantic Ocean and the low elevation. Sea level rise is also affecting the saltwater inundation for this coastal area, as seen in the diagram below.
This diagram displays the high tide for Savannah in 2010, including the storm surge and the existing flood plain, while also including the projected saltwater intrusion path, the storm surge and the flood plain for 2050. As sea level rise moves inland, the saltwater also infiltrates the land causing the root systems of non-salt-tolerant plants to dehydrate, leaving them to suffocate and die prematurely.

The sites for this thesis were limited to residential properties ranging from the coast to the mainland as they all face the threat of storm surge and rising sea level within the next century. Although the urban center of Savannah is at risk for flooding from

storms, the main source of issue is due to the outdated stormwater management practices.

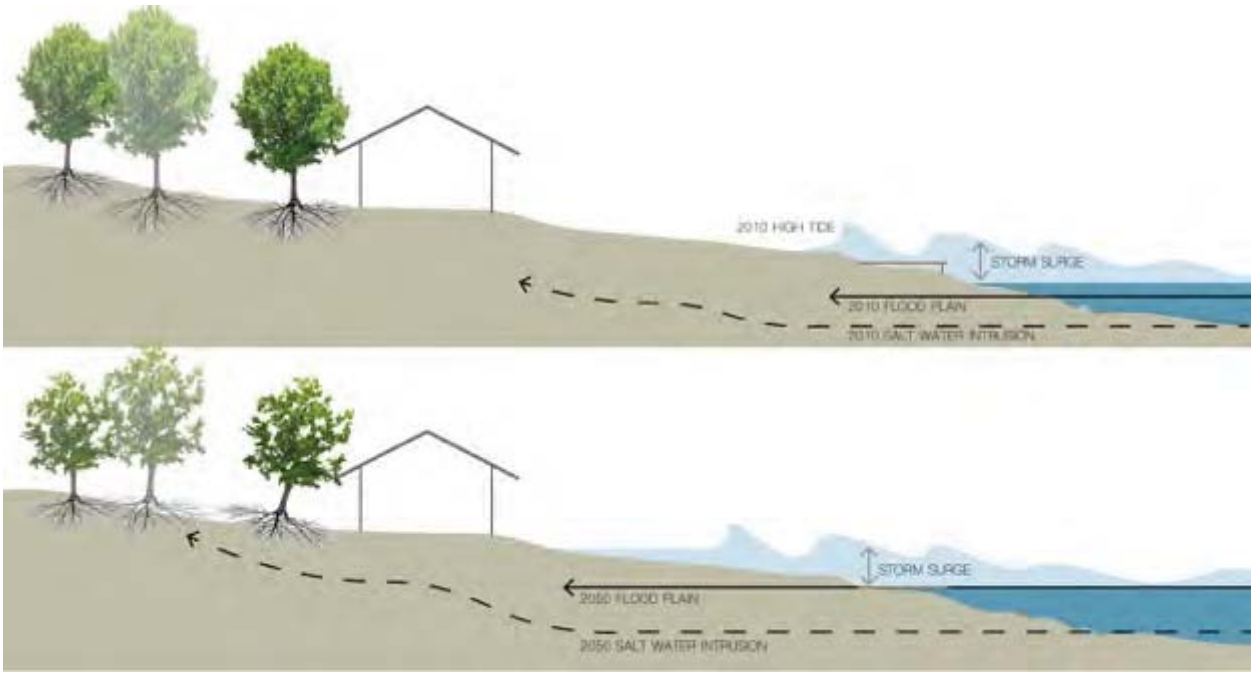


Figure 7. Savannah Inundation (Valdes 2017)

When choosing locations in Savannah, the coast was ideal because of the miles of residential and commercial areas that are on the shoreline. The coastline of the barrier islands within Chatham county are constantly being affected by salt spray, storm surge and blue-sky flooding, which make them ideal for salt-tolerant and wind tolerant designs.

The wetlands are defined by “areas where water covers the soil or is present either at or near the surface of the soil all year or for varying periods of time during the year” (EPA 2017). The Marshland was chosen as an area of interest for this thesis because (x) amount of Chatham County is made up of natural wetland ecological systems. It was also chosen based on the natural processes that provide protection from storm surge. Marshes trap and “slowly release” surface water, flood water and rain (EPA 2017), which make it

ideal for natural line of protection.

The inland scenario was important to include in the design process for the significant amount of inland residential homes in Savannah. These areas are prone to issues from flooding and as sea level rises, the coastline erodes, shifts and changes, which will cause storm surge to affect areas previously untouched.

In the mainland, Savannah, the orientation and proximity to the coastline will be affected by rising sea levels. Within the century, a 3-foot sea level rise will severely alter the existing conditions of Savannah. Because of this, the importance of designing for mainland scenarios is vital when considering the altering climate.

Delimitations:

When choosing hypothetical study sites, (coastal, marshland, inland and mainland), it is necessary to acknowledge the existence of flood prone areas in Savannah, which are unpredictable but for this thesis, it develops a generalized guidance which led to the focus on a simple location framework.

Orientation and exposure relative to prevailing winds is an issue for any coastal city, however, for this thesis, it was simplified to coastal has more wind and salt exposure, marshland has more salt inundation exposure, and finally, inland and mainland have less wind and salt exposure.

Also, in these scenarios, the property owners and residents are often faced with number choices for ground cover, however, this thesis considers the most common, turf grass, to be the default in each representation. The focus of this thesis is on native Georgia coastal herbaceous, shrubs, and trees materials for their characteristics of resistance to salt spray and wind damage.

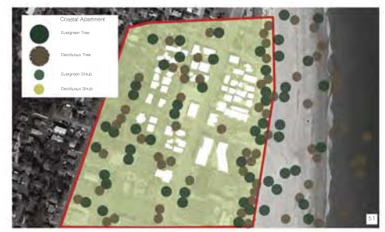
TABLE 1 MATRIX	Individual	Duplex	Large Apart.	Neighborhood
Coastal				
Marshland				
Inland				
Mainland				

Table 1 introduces the breakdown of the different locations chosen for the designs, as well as the type of residential conditions. Each condition present represents the best management practice of protecting against sea level rise and storm surge. As the chart moves inland and to the neighborhood scale, the design conditions require less salt-tolerant plants, and less plants for overall maintenance.

TABLE 2 PLANT LIST

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure
Normal to Moist Soil					
Trees (Evergreen)	Magnolia grandiflora	Southern Magnolia	Medium	60'-80' x 30'-50'	Full Sun to Partial Shade
	Sabal palmetto	Cabbage Palm	Low	50' x 70'	Full Sun to Partial Shade
Trees (Deciduous)	Amelanchier arborea	Common Serviceberry	Low	15'-25' x 15'-25'	Full Sun to Partial Shade
	Carya tomentosa	Mockernut Hickory	Low	60'-80' x 40'-60'	Full Sun to Partial Shade
	Celtis laevigata	Sugarberry	Low	60'-80' x 60'-80'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Moist Soil					
Shrubs (Evergreen)	Morella cerifera	Wax Myrtle	Low	10'-15' x 8'-10'	Full Sun to Partial Shade
	Myrcianthes fragrans	Simpson's Stopper	Low	6' x 8'	Full Sun to Partial Shade
Shrubs (Deciduous)	Callicarpa americana	American Beauty Berry	Medium	3'-6' x 3'-6'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Moist Soil					
Perennials	Baptisia australis	False Indigo	Low	3'x3'	Full Sun
	Heliotropium curassavicum	Seaside Heliotrope	Low		Full Sun to Partial Shade
	Limonium carolinianum	Sea Lavender	Low	2'-3' x 3'-5'	Full Sun
	Pontederia cordata	Pickerel Weed	Medium	2'-4' x 1.5'-2'	Full Sun
	Sabatia dodecandra	Marsh Rose Gentian	Medium		Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Moist Soil					
Ferns	Polystichum acrostichoides	Christmas Fern	Low	1'-2' x 1'-2'	Part Sun to Full Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Moist Soil					
Grasses, Sedges and Rushes	Juncus roemerianus Scheele	Black Needlerush	Low	4' - 7'	Full Sun
	Salicornia	Glasswort	Low	4" - 20"	Full Sun
	Spartina bakeri	Sand Cordgrass	Low	4' - 6'	Full Sun
	Spartina patens	Saltmeadow Cordgrass	Low	4' -6'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Moist Soil					
Vines (Deciduous)	Ipomoea sagittata	Saltmarsh morning-glory	Low	3' x 4'	Full Sun
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Well Drained Soil					
Trees (Evergreen)	Juniperus virginiana	Eastern Red Cedar	Low	30'-65' x 8'-25'	Full Sun
	Sideroxylon tenax	Tough Bully	Low to Medium	12'-30' x 20'	Full Sun to Partial Shade

Trees (Deciduous)					
	Fagus grandifolia	American Beech	Low	50'-80' x 40'-80'	Full Sun to Partial Shade
	Gleditsia triacanthos	Thornless Honey Locust	Medium	60'-80' x 60'-80'	Full Sun
	Quercus chapmanii	Chapman's Oak	Medium	15'-25' x	Full Sun
	Quercus geminata	Sand Live Oak	Low	30' x 40'	Full Sun to Partial Shade
	Quercus virginiana	Live Oak	Low	40'-80' x 60'-100'	Full Sun
	Zanthoxylum clava-herculis	Southern Prickly Ash	Low	15'-30' x 10'-25'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Well Drained Soil					
Shrubs (Evergreen)	Baccharis halimifolia	Eastern Baccharis	Low	10' x 5'	Full Sun to Partial Shade
	Ilex vomitoria	Yaupon Holly	Medium	10'-20' x 8'-12'	Full Sun to Partial Shade
	Serenoa repens	Saw Palmetto	Low	7' x 7'	Full Sun to Partial Shade
	Yucca filamentosa	Adam's Needle	Low	4'-8' x 2'-3'	Full Sun
Shrubs (Deciduous)					
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Well Drained Soil					
Perennials	Helianthus debilis	Dune Sunflower	Medium	8'-10' x 1'-3'	Full Sun
	Solidago sempervirens	Seaside Goldenrod	Low	3' x 6'	Full Sun
	Baptisia 'Carolina Moonlight'	Carolina Moonlight False Indigo	Low	3'-4' x 3'-4'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Well Drained Soil					
Grasses, Sedges and Rushes	Muhlenbergia capillaris	Pink Muhly Grass	Low	2'-3 x 2'-3'	Full Sun to Partial Shade
	Uniola paniculata	Sea Oats	Low	2' x 6'	Full Sun to Partial Shade
	Botanical Name	**Common Name**	**Maintenance**	**Height x Width**	**Sun Exposure**
Normal to Well Drained Soil					
Vines (Deciduous)	Ampelopsis arborea	Peppervine	Low	12' - 15'	Full Sun to Partial Shade
	Passiflora incarnata	Purple Passionflower	Low	12' - 25'	Full Sun to Partial Shade

Table 2 suggests a salt-tolerant plant list that is best suited for Savannah, Georgia. Each plant is broken down by level of salt tolerance (highly to moderately), and further broken down by type (i.e. trees, shrubs, palms, ornamental grasses, and perennials). As conditions for length of inundation and societal attachment will vary as the site does. Sources of plant materials are indicated in Table 3.

TABLE 3

PLANT SOURCES

Floridata	https://floridata.com/
Florida Palm Trees	http://www.florida-palm-trees.com/
Foraging Texas	http://www.foragingtexas.com/
Missouri Botanical Garden	http://www.missouribotanicalgarden.org/
Monrovia	https://www.monrovia.com/
USDA	https://plants.usda.gov/java/

CHAPTER 5

THE DESIGNS

The designs in this thesis address environmental stressors, from both natural and anthropogenic sources, on the city of Savannah. Savannah's coastal zones are dynamic and subject to changing environmental conditions caused by climate variations such as flooding, storm surges, hurricanes, winds, changes in sea level, and changes in temperature and rainfall regimes. At the same time, Savannah is subject to increasing human population and development in coastal areas has increased hydrological alteration, coastal pollution, and habitat destruction. Change in coastal ecosystems can be very rapid (for example, as the result of a severe storm). Thus, a central question for landscape architects and land managers in Savannah is how to proactively manage and/or restore coastal lands in a future of changing climate, land use, and shoreline modification. The designs in this thesis provide a framework for assessing and carrying out restoration interventions in Savannah areas degraded by changing climate conditions.

Savannah incorporates coastal lands, marshlands, inland areas, and mainland areas and within each land type there are neighborhoods, apartment complexes, duplexes, and single-family homes that require restoration interventions – resulting in 16 land use scenarios. This thesis presents design propositions for each of the 16 land use scenarios and each design ensures low maintenance for and protection of the residents living in a given condition. The designs take into account the conditions' wide range in number of residents as well as differences in level of risk of environmental, economic, and social damage. The factors informing the designs for each land use condition are detailed below.


Coastal Individual
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Coastal Individual Home:

Love living on the coast? Well, here's your chance! This cozy single-family home is located on the ocean-front, with access to the beach. Recently added is a beautiful landscape that offers more than just spring blooming flowers; it provides shade for the residence, protection from the storm surge, and protect the eroding beach edge. Designed with resilience in mind, this landscape uses native, salt tolerant plants to protect your home from the increasing frequent super storms and tidal flooding.

Coastal Individual Home: The recent surge in development of coastal single-family homes in Savannah means that there are more units at major risk of damage due to sea level rise and frequent super storms. The barrier islands, in particular, have been overwhelmed in the past few decades with coastal residential development. During storms, coastal areas like Savannah can face extreme storm surge that results in severe flooding, especially on the barrier islands. During hurricanes or other periods of dramatic storm surge, important routes to and from affected areas can become flooded, stranding residents from aid. To combat this, roadways and driveways were designed in Topmix Permeable, a porous concrete with a unique ability to absorb up to 4,000 liters of water in 60 seconds, was therefore used in this design to allow water from storm surge to drain almost instantly. These designs also incorporated a boundary of sturdy plant life as another line of defense to protect the property. Many plant species that grow natively in coastal areas have developed specific attributes to help them survive harsh environments. These include high growth rates, dense root systems, low profiles, and high flower and seed production rate. Plants for the coastal single-family home scenario were chosen based on these qualities. Those species that were especially wind, salt, and moisture tolerant were placed in areas that are prone to damage during a storm, generally the parts of the property at lower

elevation. In U.S. Department of Agriculture hardiness zones 8 and (where Savannah is located), Wax Myrtle (Morella cerifera[e]) and Simpson's Stopper (Myrcianthes fragrans[g]) are hardy evergreens and require little maintenance for the average homeowner. It is a plant that grows up to only five feet and, when planted close together, can provide a screen of protection against natural elements. Therefore, Wax Myrtle (Morella cerifera[e]) and Simpson's Stopper (Myrcianthes fragrans[g]) were planted close to the borders of the single-family property. This was also because of its preference for full sunlight and its high tolerance for sandy soil conditions, so it will thrive near the beach. American Beautyberry (Callicarpa Americana) was also introduced into the coastal single-family home scenario because it is hardy, medium level to maintain, has a high growth and propagation rate, and is salt tolerant. In this design, Sea Oats (Uniola paniculata[f]) and Adam's Needle (Yucca filamentosa[e]) was planted close to the residence as it protects and slows the rate of inundation for the property. Christmas Ferns (Polystichum acrostichoides[d]) were placed along the coastline as a method to slow the rate of erosion. When placed on the steep slopes of the beach and on sloped regions of the single-family property, Holly Ferns slows erosion because their rapidly-growing root system forms a crisscross pattern that holds the soils and organic matter in place. Additionally, Live Oaks (Quercus virginiana[h]), Sand Live Oaks (Quercus geminata[a]), Eastern Red Cedars (Juniperus virginiana[d]) and Sugarberry (Celtis laevigata[d]), and Mockernut Hickory (Carya tomentosa[h]) were introduced to the single-family home site because, as previously discussed, they are highly salt tolerant and prefer full sunlight exposure. Though not as important for the single-family scenario, they are also low-maintenance.


Coastal Duplex
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Coastal Duplex Home:

A dream ocean-front duplex is just around the corner, with a beautifully resilient landscape installed to protect your home from storm surge, and wind damage we have experienced. The north end of the duplexes is protected by a dense planting plan that also prevent further erosion of your beach front property.

Coastal Duplex Home: The coast of Savannah is eroding at a rapid pace due to climate change-driven sea level rise and the increase in storm strength. For the coastal duplex scenario, plants were chosen for their high tolerance for heavy sea salt spray, moist soil, and short-to-long term inundation. As in the coastal apartment complex scenario, Mockernut Hickory (Carya tomentosa$_h$), Cabbage Palm (Sabal palmetto$_b$), and Sugarberry (Celtis laevigata$_d$) were introduced on this property for their viability in moist, salty conditions. American Beautyberry (Callicarpa Americana), Saltmeadow Cordgrass (Spartina patens$_f$), Sand Cordgrass (Spartina bakeri$_a$), Saltmarsh Morning Glory (Ipomoea sagittata), and Sea Oats (Uniola paniculata$_f$) were also chosen for this scenario. These species in particular are very easy to grow in full sun to partial shade and in moist to dry soil. Christmas Ferns (Polystichum acrostichoides$_d$) were also introduced as they are often used on slopes to prevent erosion so are ideal for prevention of eroding coastal conditions. Wax Myrtle (Morella cerifera$_e$), an evergreen was introduced to the site for its high tolerance for salt-spray year-round, as well it is aesthetic color during the bloom time. It is easy to care for the plants chosen because they do not require much pruning. The designs call for these plants to be introduced as young transplants (as opposed to seedlings) because of the stabilization this provides for coastal environments. Furthermore, transplants mean that the plants mature sooner, leading not only to quicker property protection but also to a more marketable landscape in the case of tenant turnover.


Coastal Apartment
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Coastal Apartment Complex:

Steps away from the beaches of Savannah is your dream apartment! Recently updated, the community spaces of the complex introduce winding paths of aesthetic and protective salt tolerant plants. It brings you into a world of dense plantings, while feet from the sandy shores of the coast. What a way to enjoy the natural amenities of the Savannah?

Coastal Apartment Complex:

In human-dominated landscapes, natural and anthropogenic environmental stressors frequently overlap and sometimes have catastrophic consequences for both natural and human systems. Because of inferior building materials, apartments are frequently less resilient than single-family homes to shocks such as flooding, storm surge, hurricanes, and high-force winds. They also run a risk of being forgotten in the rush to save the millions of dollars in privately owned, individual-home real estate investments on the waterfront. Importantly, apartments are frequently lower-income households, meaning that damage such as flooding, which often displaces families disproportionately affects lower-income communities. According to the U.S. Census Bureau, in 2010, there were 53,750 rental units in Savannah, making up 39.8% of the housing market.


Coastal Neighborhood
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Coastal Neighborhood:

Here, in Savannah, a sense of community is around every corner. The neighborhoods located on the coast provide a unique experience, while filled with natural amenities for all walks of life. Wide ranges of plantings are provided on the edges of the beach to ensure the experience, as well as the protection against storm surge and wind damage. If you're looking for a strong sense of community and protection, then stop by, you won't want to leave!

Coastal Neighborhood:

The neighborhood condition on the coast required an extensive reestablishment of plants. Many areas of this community were facing extreme consequences from storm surge, which, according to Hurricane Matthew interviews conducted, caused damage that was unprecedented. Therefore, the plants chosen for the coastal neighborhood were based on their ability to withstand heavy sea salt spray and salt inundation during storms, as well as the ability to withstand rising saltwater tables and their maintenance. As previously discussed, Live Oaks (Quercus virginiana$_{h}$), Sand Live Oaks (Quercus geminata$_{a}$), Cabbage Palm (Sabal palmetto$_{b}$), Sugarberry (Celtis laevigata$_{d}$), Christmas Ferns (Polystichum acrostichoides$_{d}$), and American Beautyberry (Callicarpa Americana), Saltmeadow Cordgrass (Spartina patens$_{f}$), Sand Cordgrass (Spartina bakeri$_{a}$), Sea Oats (Uniola paniculata$_{f}$), and Seaside Heliotrope (Heliotropium curassavicum$_{h}$) were placed to create a protective boundary around the community. The plants provided slow the rate of storm surge inundation as well as reduce the damage caused by wind during hurricanes and storms. The edges created protect the residents from frequent flooding of the rising number of king tides as well. Topmix Permeable was also designed to replace the existing roadways. Many residents of the barrier islands stated the frequent flooding during storms, and the safety issues that follow. Topmix Permeable allows gallons of water to be

infiltrated and inundated into the top layer, which is relatively large pebbles, followed by an attenuation layer for further infiltration. The roadways of the coastal neighborhoods would be more accessible during storms.


Marsh Individual
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Marsh Individual Home:

Paradise in Savannah! This waterfront property provides an experience unique to its own. A recently updated landscape has provided resiliency for this property, while also providing a beautiful scene of lush, dense plantings that draws your eye around the property. Resiliency was used as the basis for design, to protect against rising sea level and tidal flooding.

Marsh Individual Home:

Overdevelopment of the coast also affects the marshlands of Savannah, particularly in terms of pollution. Marshlands protect adjacent residential areas from storm, wave, and flood damage while also helping to sustain productive fisheries and wildlife, but if they flood during superstorms, they cannot do their job. Preserving marshlands is cost-effective for existing businesses and nearby single-family homes. It is far more expensive, often less effective, and sometimes impossible, to developing engineered alternatives to the water quality, water storage, and flood protection functions provided naturally by marshlands. Therefore, for this design, single-family homes near marshes were replanted with salt-tolerant plants that have the ability to be inundated by the marsh water for long periods of time. Cabbage Palm (Sabal palmetto[b]), Mockernut Hickory (Carya tomentosa[h]), Thornless Honey Locust (Gleditsia triacanthos[e]), Sea Lavender (Limonium carolinianum[e]), Pickerel Weed (Pontederia cordata[d]), Yaupon Holly (Ilex vomitoria[h]), Sand Live Oak (Quercus geminata[a]), and Saw Palmetto (Serenoa repens[g]), and Sea Oats (Uniola paniculata[f]) were also placed on the site for the same reasons previously discussed for apartment complexes and duplex near marshlands. Seaside Goldenrod (Solidago sempervirens[f]) was also introduced based on its tolerance for very moist soils at a wide range of salinities. American Beautyberry (Callicarpa Americana), an upright deciduous shrub, was planted in the sandy soil on the border of the property as a physical line of protection against

storm surge. This bush, which natively occurs in moist woodlands close to water, prefers acidic, moist but well-drained soil rich in organic matter. Being multi-stemmed and growing 5 feet to 8 feet tall and 4 feet to 6 feet wide, they can form colonies that act as a wall. Lastly, this design introduced Big Leaf Hydrangea onto the site because of its fast growth rate and moist soil preference.


Marsh Duplex
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Marsh Duplex:

Are you looking for a cozy home with a view unlike any other? Then look no further! This property is a sophisticated, unique retreat that reflects innovation and landscape architecture. Newly added are salt tolerant plants that were placed within this property to protect this duplex. Super storms will not stand a chance to this home and yard!

Marsh Duplex:

Overdevelopment is a threat to the structural integrity of Savannah marshes and wetlands. However, the thoughtful introduction of native species well suited to changing conditions can be very effective in reestablishment of these lands, thus protecting residents who live near them. As in the apartment complex scenario, marshlands themselves are fairly unlikely locations for duplex developments. However, many duplexes do exist near marshy areas. The duplex necessitates plant life that can withstand high salt levels, high soil moisture levels, and high-to-full sunlight levels. They must be able to handle long periods of soil inundation. The plants introduced on the duplex property are evergreen and require low maintenance. Similar to the marshy apartment complex scenario, Live Oak (Quercus virginiana$_{h}$), Cabbage Palm (Sabal palmetto$_{b}$), Sugarberry (Celtis laevigata$_{d}$), and Seaside Heliotrope (Heliotropium curassavicum$_{h}$), Tough Bully (Sideroxylon tenax$_{f}$), and Mockernut Hickory (Carya tomentosa$_{h}$) were included for their tolerance for salt water inundation. Simpson's Stopper (Myrcianthes fragrans$_{g}$), which is evergreen, moderately salt tolerant, and which thrives in moist soil, was also planted on the duplex property. Sea Oats (Uniola paniculata$_{f}$) and Saltmarsh Morning Glory (Ipomoea sagittata) were also included on site, as it has relatively low maintenance. It can grow in moist-well drained soil and requires full sun. Sea Oats (Uniola paniculata$_{f}$) and Saltmarsh Morning Glory (Ipomoea sagittata) were chosen and placed on site for their salt-tolerant qualities, which makes

it easy for the residents of the duplex to maintain. Sea Oats (Uniola paniculata$_f$) and Saltmarsh Morning Glory (Ipomoea sagittata) require full sun and can be inundated by saltwater for a short amount of time. Yaupon Holly (Ilex vomitoria$_h$) was introduced on site for similar reasons. Preferred growing conditions of Yaupon Holly (Ilex vomitoria$_h$) include moist, but well-drained, soil rich in organic matter (as in a marshland). It is fast growing (4 to 6 inches per year), so it can be established quickly. Despite its preferences, Yaupon Holly (Ilex vomitoria$_h$) will also tolerate sandy or heavy clay soils, moderate drought and air pollution. These qualities make it an ideal plant for urban areas. Both Sea Oats (Uniola paniculata$_f$) and Saltmarsh Morning Glory (Ipomoea sagittata) are difficult to transplant in their mature states; thus, they will be established as seedlings in this scenario.


Marsh Apartment
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Marsh Apartment Complex:

A property that is conveniently located on the marsh of Savannah this apartment complex encompasses the use of salt tolerant plants in a newly developed landscape. Each plant was designed with your changing coastline needs in mind! These plants will protect any apartment complex from storm surge and king tides, so be prepared to love it here for long time!

Marsh Apartment Complex:

Almost a third of the Atlantic Coast's tidal salt marshes are located in the Georgia's Lower Coastal Plain. Here, salt marsh ecosystems are generally found in estuaries along and behind barrier islands such as Tybee Island, as well as along the sides of larger estuary systems like the Savannah River. Because marshes are connected directly to the ocean, tides continually move salt water into and out of salt marshes systems. Generally, salt marshes protect shorelines from erosion by creating a buffer against wave action and by trapping soils mobilized by storm surge. In flood prone areas, salt marshes reduce the flow of flood waters and absorb rainwater.

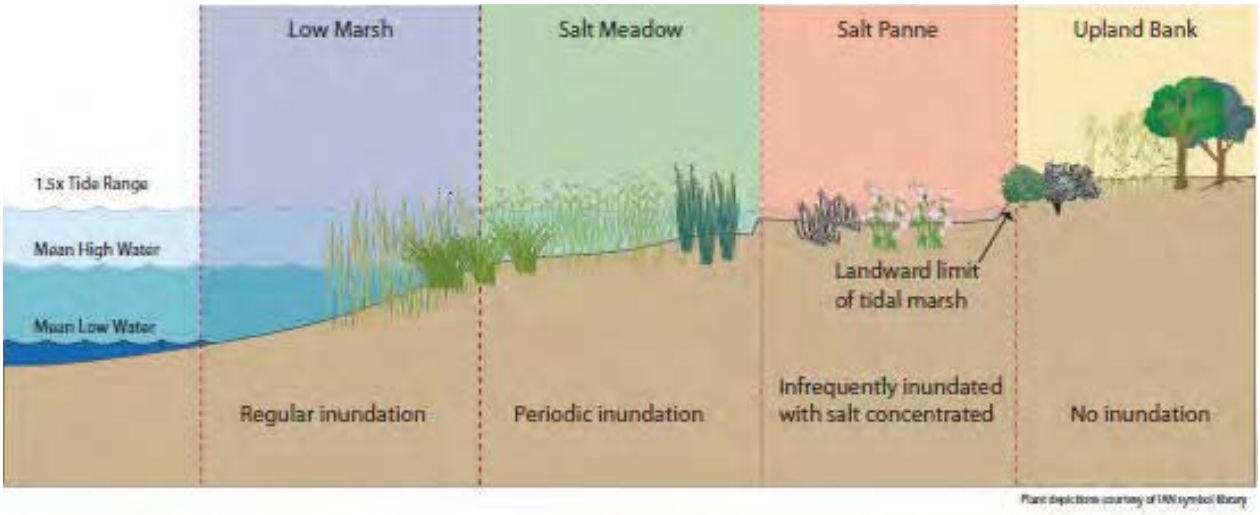
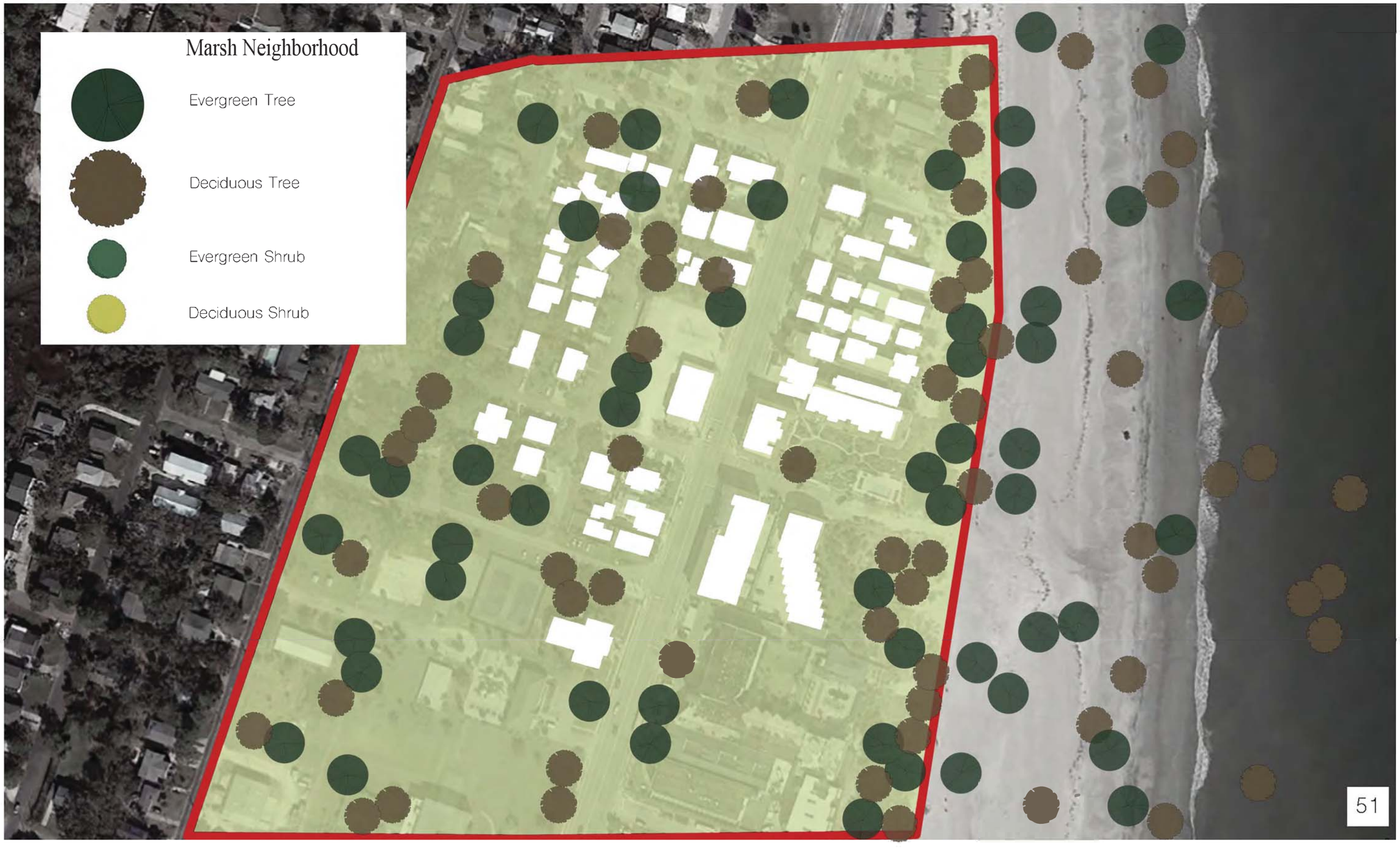


Figure 8. Example of Center for Coastal Resources Management (Living Shorelines 2017)

However, climate change is predicted to increase the severity of storms, thereby heightening flooding, storm surge and soil inundation risks for areas near marshlands. While marshlands in Georgia are themselves not generally home to many residents, apartment complexes in proximity to marshes do exist. Therefore, for this condition, apartment complexes were particularly designed to protect the structures and the residents that live in them from flooding, storm surge, and soil inundation. Because marshes are dynamic systems with varying levels of salinity depending on the tides and amount of rainfall, plants chosen for apartment complexes near marshes were chosen based on their mid- to high-level salt tolerance, their ability to be saltwater-inundated for long periods of time, and their soil moisture preferences. Seaside Goldenrod (Solidago sempervirens$_f$), Pickerel Weed (Pontederia cordata$_d$), Seaside Heliotrope (Heliotropium curassavicum$_h$), Sea Lavender (Limonium carolinianum$_e$), Tough Bully (Sideroxylon tenax$_f$), and Yaupon Holly (Ilex vomitoria$_h$) were chosen for the marshland apartment complex because of their particular ability to adapt to a wide range of soils moisture levels. Also, Eastern Baccharis (Baccharis halimifolia$_f$), Saltmeadow Cordgrass (Spartina patens$_f$) and Sand Cordgrass (Spartina bakeri$_a$) are often found in areas of high salinity, so they are ideal for marshy areas. These plants are low, unobtrusive, and inconspicuous, so they are unlikely to cause aesthetic disagreement among co-residents. As in the coastal apartment scenario, Cabbage Palm (Sabal palmetto$_b$), Mockernut Hickory (Carya tomentosa$_h$), Sugarberry (Celtis laevigata$_d$), Wax Myrtle (Morella cerifera$_e$), Thornless Honey Locust (Gleditsia triacanthos$_e$), which thrive in moist and sandy soil, were also introduced to protect against rising sea level, storm surge, and soil inundation. Sea Oats (Uniola paniculata$_f$) was also introduced in this scenario because of its high tolerance of heavy sea salt sprays and high-force winds. This

grass, native to southeastern wetlands, is easy to grow and requires little-to-no maintenance. Sea Oats (Uniola paniculata$_f$) grass also has the ability to quickly regrow after structural damage.


Marsh Neighborhood
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Marsh Neighborhood:

Neighborhoods evoke a sense of community, and here, in Savannah, community is the driving force. This neighborhood is situated on the marshland, where the breeze from the water is fresh in the air, and the plant life of False Indigo (Baptisa australis$_d$), Saltmeadow Cordgrass (Spartina patens$_f$) and Eastern Red Cedar (Juniperus virginiana$_d$) surrounds you. This neighborhood provides a sense of comfort and protection from recently increasing number of hurricanes/super storms as well as erosion, and wind damage.

Marsh Neighborhood:

Georgia's marshes are some of the most biologically productive natural systems on Earth. The enormous biological productivity of marshes makes them primary nursery areas for crabs, oysters, shrimps, and other economically important fish and shellfish. In addition, salt marshes help filters pollutants from the water and act as buffers against offshore storms. However, during super storms, there may be so much extra runoff and pollutants that marsh systems become overwhelmed and can no longer do their jobs. Therefore, it is especially important that neighborhoods located near marshes take their storm runoff situation into careful consideration. They must have healthy, thriving marshlands full of plants adapted to harsh conditions. Marshland neighborhood designs required plants that can handle very moist, salty conditions, as their likelihoods of being inundated with storm surge for long periods of time is high. As in previous scenarios, most of the grasses introduced were native to the southeastern U.S. wetlands. Reestablishing them created a salt and wind tolerant boundary for the neighborhood.


Inland Individual
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Inland Individual Home:

Dream homes are far and few between, but this historical home located in the heart of Savannah provides carefully and quality crafted details unlike any other. The updated landscape of the front and backyard are unique and innovative in protecting from the rising number of super storms and wind related damage.

Inland Individual Home:

Although single-family homes located in inland Savannah are not as prone to the risk of storm surge, high tides, and flooding as in the coastal and marshland scenarios, they are still at risk for some damage as the of magnitude of storms intensify. On these properties, it was important to choose salt-tolerant plants but not necessarily ones that can tolerate very long periods of inundation time. They can be taller than plants chosen for properties closer to the coast. Species chosen for this scenario were similar to those chosen for other inland scenarios: Mockernut Hickory (Carya tomentosa[h]), Cabbage Palm (Sabal palmetto[b]), Sand Live Oaks (Quercus geminata[a]), Live Oaks (Quercus virginiana[h]), Wax Myrtles (Morella cerifera[e]), Southern Magnolias (Magnolia grandiflora[d]), and Eastern Red Cedars (Juniperus virginiana[d]) were planted for their moderate-to-high salt tolerance and for their resiliency under various sunlight exposure levels. Additionally, American Beautyberry (Callicarpa Americana), and Saltmeadow Cordgrass (Spartina patens[f]), Sand Cordgrass (Spartina bakeri[a]), Saw Palmetto (Serenoa repens[g]) and Sea Oats (Uniola paniculata[f]), which all prefer light shade, were placed under the canopy of larger trees. Thornless Honey Locusts (Gleditsia triacanthos[e])were also placed on site for their excellent reestablishment qualities, as well as their draw for full-sun. Thornless Honey Locusts (Gleditsia triacanthos[e]) easily adapt to different soils, as they are often placed in cityscapes, as well as parks. Although they are not evergreens, they provide

exceptional fall color, and can tolerant a significant amount of salt-spray. Seaside Heliotrope (Heliotropium curassavicum$_h$) and Saltmarsh Morning Glory (Ipomoea sagittata) were placed into the design based on their ability to withstand significant salty soils, as well as salt-spray. They require very little maintenance and prefer full sunlight exposure.


Inland Duplex
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Inland Duplex Home:

A southern charm duplex is waiting for a family like yours! This duplex located inland is walking distance to the historic district of Savannah. This recently updated duplex is home to a wide variety of salt tolerant plants that are specifically used for the rising number of super storms and wind related damage. Each plant was placed in areas to protect the home and will keep the integrity of this unique property.

Inland Duplex Home:

Though not as likely as in the coastal scenarios, duplexes which are located inland may also be subject to the effects of super storms, especially flooding caused by king tides. Duplexes and surrounding ecosystems may be subject to damage if their lines of protection are compromised. In designing the inland duplex, it was vital to include salt tolerant plants that can be inundated for short periods of time before flood waters retreat. For the inland duplex scenario, Wax Myrtles (Morella cerifera$_e$), Sand Live Oaks (Quercus geminata$_a$), Live Oaks (Quercus virginiana$_h$), Simpson's Stopper (Myrcianthes fragrans$_g$), and American Beautyberry (Callicarpa Americana) were chosen for these qualities. These species also tolerate a range of sun conditions – crucial, as not all duplexes are subject to the same degrees of light. Eastern Red Cedars (Juniperus virginiana$_d$), which are 30-50 feet tall on average and do require full sun, were placed along the street, where they are more likely to receive it.


Inland Apartment
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Inland Apartment Complex:

Are you in the market for an apartment that encompasses downtown living, while still walking distance from the water? Then you have entered your dream location! This apartment complex offers a lavish landscape of shrubs and flowers with rich colors that glide your eyes. With the increasing frequent super storms and tidal flooding, your apartment will be a safe haven with a landscape unlike any other.

Inland Apartment Complex:

Inland areas of Savannah are not subject to the same risk of flooding, storm surge, and soil inundation as coastal or marshland areas. However, plants in inland Savannah still need to be somewhat moisture tolerant and able to handle soil inundation with saltwater for short periods of time, especially with expected climate-driven super storms and resultant flooding. The plants for the inland apartment complex scenario were also chosen based on their ability to decrease the rate of soil inundation and their ability to quickly regrow after super storms. For this design, these sorts of plant species were placed in areas that have historically experienced serious flooding due to storm surge, according to recent mapping projects and personal accounts from Hurricane Matthew and Irma. One such plant is Southern Magnolia (Magnolia grandiflora$_d$), a medium-to-large sized, fast-growing evergreen tree commonly found in the southeastern United States. It is identified as requiring medium maintenance, which is why it is included for apartments. American Beautyberry (Callicarpa Americana) was also introduced in the apartments for its medium maintenance level. Sugarberry (Celtis laevigata$_d$), False Indigo (Baptisia australis$_d$), Marsh Rose Gentian (Sabatia dodecandra$_f$), Saltmeadow Cordgrass (Spartina patens$_f$), Sand Cordgrass (Spartina bakeri$_a$), and Saltmarsh Morning Glory (Ipomoea sagittata) are ideally suited for apartment communities because they are long-lived and relatively

free from disease and insect problems, therefore requiring little maintenance. They also withstand a range of moisture conditions (once established). These grasses and shrubs are relatively well-adapted to a broad range of soil conditions and thrive in both well-drained and moist soils, which is ideal for handling the effects of flooding and storm surge. Planted together, they make a large hedge or screen, ideal for apartment privacy. Other plants chosen for the apartment complex scenario include: Simpson's Stopper (Myrcianthes fragrans$_{g}$), Wax Myrtles (Morella cerifera$_{e}$), Eastern Red Cedars (Juniperus virginiana$_{d}$), Sand, and Live Oaks (Quercus virginiana$_{h}$). In addition to fulfilling the requirements laid out above, they were also chosen for their relatively low maintenance.


Inland Apartment
Inland Neighborhood
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Inland Neighborhood:

There is no place like neighborhood! If you're in the market for an area filled with rich green spaces, luscious winding paths and natural amenities, then do we have a neighborhood for you! Unlike any other area in Georgia, this coastal community thrives on the easy-going pace of life, the beautiful scenery and the unique residents. This inland neighborhood has been developed with salt tolerant plants that are deep-rooted in their culture as well as the plants themselves! Come on down and check out this neighborhood unlike any other.

Inland Neighborhood:

Inland neighborhoods are at special risk of environmental damage by polluted runoff, as described above. Inland neighborhoods are often bigger than ones on the coast or near marshland. With increased space comes increased number and size of roads within the neighborhood, more driveways, and possible parking lots if the neighborhood includes community centers or shops. In the design for this scenario, Topmix Permeable was used for all paved surfaces. More than in the coastal or marshland neighborhood scenarios, storm runoff in inland neighborhoods are subject to pollution because the population is higher. This means more pollutants (from the large number of cars, from the chemicals residents use on their properties, etc.). Plants chosen for this scenario include Cabbage Palm (Sabal palmetto$_b$), Mockernut Hickory (Carya tomentosa$_h$), Sand Live Oak (Quercus geminata$_a$), Live Oak (Quercus virginiana$_h$), Sea Oats (Uniola paniculata$_f$), Common Serviceberry (Amelanchier arborea$_d$) were introduced on site for their salt tolerance, salt inundation tolerance, salt-spray, as well as their ability to be reestablished. False Indigo (Baptisia australis$_d$), Saltmeadow Cordgrass (Spartina patens$_f$), Marsh Rose Gentian (Sabatia dodecandra$_f$), and Sand Cordgrass (Spartina bakeri$_a$) were also placed on site for the same reasons as previously discussed. American Beech (Fagus

grandifolia[d]), Chapman's Oak (Quercus chapmanii[f]), and Saw Palmetto (Serenoa repens[g]) were also placed in between the property and the marsh, as its tolerance for being in moister soil, and tolerance for salt-spray and preferred full sunlight exposure.


Mainland Individual
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Mainland Individual Home:

This home, located just a few short minutes from the beaches of Savannah has been restructured with a luxurious backyard. This magnificent waterfront residence is graced with the large canopies of Sand Live Oaks (Quercus geminata[a]), Cabbage Palms (Sabal palmetto[b]), Thornless Honey Locust (Gleditsia triacanthos[e]) and many more rich plants to provide privacy and protection against storm related damage as the number of super storms and tidal flooding rise.

Mainland Individual Home:

Mainland Savannah single-family homes are not as subject to high winds, which can cause plant structural damage and dehydration, or inundation with salty storm surge as the coastal or marshland scenarios, but they still need to incorporate resistant plant species in the case of a large enough disaster and a change in how the environment handles stressors. Plants chosen for mainland Savannah single-family homes need to be able to handle moderate moisture levels and short periods of saltwater inundation. Therefore, for the mainland duplex scenario, Live Oaks (Quercus virginiana[h]), Wax Myrtles (Morella cerifera[e]), and Eastern Red Cedars (Juniperus virginiana[d]) were chosen. These trees also provide privacy for the single-family property, large amounts of shade, and require very limited maintenance once established. Dune Sunflower (Helianthus debilis[f]), Carolina Moonlight False Indigo (Baptisia australis[d]), Pinky Muhly Grass, Peppervine (Ampelopsis arborea[c]) and Purple Passionflower (Passiflora incarnata[h]) were introduced for their high salt tolerance, as well as their resistance to wind, and lastly, for their medium maintenance level as individual homes have more accessibility to maintain the property.


Mainland Duplex
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Mainland Duplex:

This memorable duplex encompasses the historic charm of downtown Savannah with close proximity to the beachfront. A beautiful lush landscape was recently added to this duplex with Southern Prickly Ash (Zanthoxylum clava-herculis$_d$), Saw Palmetto (Serenoa repends$_g$), Pink Muhly Grass (Muhlenbergia capillaris$_e$) and many more to fill the space with different experiences each step of the way.

Mainland Duplex:

Plants chosen for mainland Savannah duplexes need to be able to handle moderate moisture levels and short periods of saltwater inundation. They must also tolerate high winds because winds can cause structural damage and dehydration of plants. Therefore, for the mainland duplex scenario, Mockernut Hickory (Carya tomentosa$_h$), Live Oaks (Quercus virginiana$_h$), Wax Myrtles (Morella cerifera$_e$), Thornless Honey Locust (Gleditsia triacanthos$_e$), Chapman's Oak (Quercus chapmanii$_f$) and Tough Bully (Sideroxylon tenax$_f$), Eastern Red Cedar (Juniperus virginiana$_d$), Yaupon Holly (Ilex vomitoria$_h$), and Saw Palmetto (Serenoa repens$_g$) were chosen. These trees also provide privacy, large amounts of shade, and require very limited maintenance once established.


Mainland Apartment
Evergreen Tree
Deciduous Tree
Evergreen Shrub
Deciduous Shrub

Mainland Apartment:

Ever wonder where you would find your dream apartment? Look no further! A unique apartment complex with an illustrative, dense garden and surrounding plants is right around the corner from you. With the number of super storms increasing, the plants of this luxurious apartment ensure the safety and integrity of the changing Savannah area.

Mainland Apartment:

According to predictions of the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA) as well as the National Aeronautics and Space Administration (NASA) and the Intergovernmental Panel on Climate Change (IPCC), Savannah mainland areas, like coastal, marshland, and inland areas, are also threatened by increased frequency and intensity of super storms and resultant flooding. During recent hurricanes Matthew and Irma, the mainland of Savannah was bombarded with severe winds (gusts up to 70 mph) and storm surge that reached up to 4.7 feet (EPA 2017). A king tide, as it's known colloquially, is an especially high tide that coincides with a full moon. Unfortunately, it also coincided with Irma, and the storm surge combined with the tide resulted in swells of up to 15 feet (interview conducted, 2017). This is a prime example of why plants chosen for even mainland Savannah apartment complexes need to be able to handle high winds and moisture levels. High winds can cause plant structural damage and dehydration. Inundation by salty storm surge also contributes to plant dehydration. Therefore, within the courtyards of mainland apartment complexes, trees which are highly salt tolerant, such as Southern Magnolias (Magnolia grandiflora$_d$), Eastern Red Cedar (Juniperus virginiana$_d$), Sand Live Oak (Quercus geminata$_a$), and Live Oak (Quercus virginiana$_h$), Sugarberry (Celtis laevigata$_d$), Mockernut Hickory (Carya tomentosa$_h$), Chapman's Oak (Querecus chapmanii$_f$), and Thornless Honey Locust (Gleditsia

triacanthos[e]) were placed. These trees also provide large amounts of shade and require very limited maintenance once established. Importantly, they are clumped in the apartment complex courtyards (as opposed to outside the complex or as standalone features). In this way, the surrounding apartment structure and other trees in the courtyard act as wind barriers, preventing tree trunks from breaking and falling on property. Simpson's Stopper (Myrcianthes fragrans[g]), Wax Myrtles (Morella cerifera[e]), American Beautyberry (Callicarpa Americana), Tough Bully (Sideroxylon tenax[f]), Yaupon Holly (Ilex vomitoria[h]), Saw Palmetto (Sernoa repens[g]), Adam's Needle (Yucca filamentosa[e]), Sea Oats (Uniola paniculata[f]), False Indigo (Baptisa australis[d]), Seaside Heliotrope (Heliotropium curassavicum[h]), Sea Lavender (Limonium carolinianum[e]), Pickerel Weed (Pontederua cordata[d]), Marsh Rose Gentian (Sabatia dodecandra[f]), Saltmeadow Cordgrass (Spartina patens[f]), and Sand Cordgrass (Spartina bakeri[a]) were designed on site for their qualities previously discussed. Dune Sunflower (Helianthus debillis[f]), Pink Muhly Grass (Muhlenbergia capillaris[e]), Peppervine (Ampelopsis arborea[c]), and Purple Passionflower (Passiflora incarnate[h]) were introduced on site for their extreme levels of resistance for wind, and their salt tolerance. They also have a significantly low maintenance level, which makes it ideal for apartment complexes.

Mainland Neighborhood

Mainland Neighborhood:

Are you looking for an area in mainland Savannah that is close to downtown and the beautiful coast? Then do we have a neighborhood for you! Resiliency was the key design factor for this neighborhood. Beautifully salt tolerant plants were placed in specific areas that are prone to the increasing number of super storms and wind damage. The aesthetic of the plants was chosen to represent the historical value of the trees, as well as the resiliency against the changing environment we have seen.

Mainland Neighborhood:

Increasingly, mainland area neighborhoods are not immune to the effects of storm surge and flooding. Like inland neighborhoods, they require replacement of pavement with Topmix Permeable to facilitate storm runoff absorption. In the mainland neighborhood (and in fact, in the inland neighborhood also), there is risk of power lines being taken down during powerful storms. This affects the safety of the residents not only because power is so crucial for everyday function, but because downed power lines landing in pools of water offer significant safety risks. This is another reason that storm water absorption is so important for neighborhoods. The plants chosen for this area include Wax Myrtle (Morella cerifera[e]), Eastern Red Cedar (Juniperus virginiana[d]), Sand Live Oak (Quercus geminata[a]), Live Oak (Quercus virginiana[h]) and Cabbage Palm (Sabal palmetto[b]), Common Serviceberry (Amelanchier arborea[d]), Sugarberry (Celtis laevigata[d]), American Beautyberry (Callicarpa Americana), and Chapman's Oak (Quercus chapmanii[f]) were incorporated for their significant salt tolerance, as well as their fast-growing ability once established. They were also chosen for their strong root systems, which would protect the residents from wind damage and other effects from super storms. Because Eastern Red Cedars (Juniperus virginiana[d]) and Wax Myrtle (Morella cerifera[e]) are evergreen, they

provide privacy for the residents, as previously mentioned. Pinky Muhly (Muhlenbergia capillaris[e]), Dune Sunflower (Helianthus debilis[f]), Carolina Moonlight False Indigo (Baptisia australis[d]), and Purple Passionflower (Passiflora incarnata[h]) were included based on their ability to withstand salt conditions in both the soil, as well as in the salt-spray, which is inevitable when living in a coastal city.

CHAPTER 6

DISCUSSION

Single-family:

According to the U.S. Census Bureau, in 2010, there were 81,400 single- family homes in Savannah, making up 60.2% of the housing market. These homes are distributed throughout Savanah, from the coastline to the mainland, and each scenario faces its own set of environmentally-based stressors. As opposed to apartment complexes and duplexes, single-family homes tend to be on larger pieces of land and owned by the occupant; therefore, there is frequently more freedom regarding the amount of plant life and species chosen for the property. This is both an advantage and disadvantage. It is an advantage because homeowners have more space to work with. They can choose to plant a variety of species that are adaptable to changing environmental conditions and these species don't necessarily need to be low-maintenance. However, the disadvantage is that homeowners are also free to make environmentally, and possibly economically, irresponsible decisions. Because single-family homes make up the majority of housing in Savannah and are therefore major liabilities to economic stability if disaster strikes, it is vital to make recommendations for responsible landscape design.

Duplex:

The multi-family duplex scenario has similarities in its requirements to both the apartment complex and the single-family home. Duplex units are occasionally privately owned but are more frequently owned by a landlord and rented out to tenants. They contribute to the 53,750 rental units in Savannah by 2010. Because of this, the priority for duplex landscapes (if prioritized at all) is ease of maintenance. This means that other factors, such as protection from

flooding and soil inundation are generally not priorities when choosing plant life for the property. This exposes the residents of such housing scenarios to the consequences of super storms. Therefore, designs for the duplex housing scenario used low maintenance, native plants that thrive under a range of moisture, light, salinity, and wind conditions. These plants were also chosen because they are neutral (not too polarizing) unobtrusive, and inconspicuous, so that they do not cause disagreement between duplex residents.

Apartment Complex:

In human-dominated landscapes, natural and anthropogenic environmental stressors frequently overlap and sometimes have catastrophic consequences for both natural and human systems. Because of inferior building materials, apartments are frequently less resilient than single-family homes to shocks such as flooding, storm surge, hurricanes, and high-force winds. They also run a risk of being forgotten in the rush to save the millions of dollars in privately owned, individual-home real estate investments on the waterfront. Importantly, apartments are frequently lower-income households, meaning that damage such as flooding, which often displaces families, disproportionately affects lower-income communities. According to the U.S. Census Bureau, in 2010, there were 53,750 rental units in Savannah, making up 39.8% of the housing market.

Neighborhood:

Among the destructive outcomes of land development and use are problems of impaired water quality and soil erosion in Georgia's coastal areas. Creation of impervious surfaces, such as driveways and parking lots, affects the natural flow of stormwater. Instead of being absorbed

into the soil naturally, in paved areas stormwater flows directly into ditches, streams, and wetlands. This runoff often includes pollutants, such as petroleum products from motor vehicles, particulates from brake-linings, fertilizers, and pesticides. Landscapes are composed of a variety of plants, natural ecosystems and habitats as well as the elements of human intervention. Because of the help human-driven climate change, coastlines, marshes, inland and mainland scenarios are being affected, causing severe consequences that alter the existing conditions of the once pristine landscape. More often, neighborhoods have more open spaces in between properties, and therefore have higher chances of sitting water from excess flooding and storm surge. Neighborhoods face the threat of becoming overly inundated, to the point of the existing plant life dehydrating. This can cause more damage to the properties during storms.

CHAPTER 7

CONCLUSION

There are a multitude of climate change-driven threats, including sea level rise, increase in frequency of super storms, storm surge, and king tides, compromising the environmental, structural, and social integrity of Savannah residences. These threats affect living scenarios on all scales, from single-family homes to complexes and all the way up to neighborhoods. Each scenario requires a specific set of solutions to combat these threats. It is important to develop landscape responses that tolerate increased salinity; tolerate more frequent and longer inundation; are more robust and resistant to storm damage; and offer equivalent aesthetic benefits to more traditional coastal planting choices. The most robust and long-lasting way of going about this is by taking advantage of plant properties to physically bolster the natural environment.

As it stands, Savannah landscapes are currently under-prepared for climate change-driven damage and disaster. The degree to which landscape infrastructure restoration after Hurricanes Matthew and Irma has been necessary shows that there is much to be done. Not only do disasters affect the environment and infrastructure on a primary level, but research has demonstrated that constant flooding and strong winds can permanently damage soil and plant conditions, leading to environmental instability – which affects communities on a deeper, more enduring level.

The introduction of salt tolerant and structurally robust plants has the potential to the reinstate the environmental integrity of residential communities. It might seem that restricting residential designs to including specifically salt tolerant plants is limiting. However, there is actually an extensive enough selection of suitable plants to provide a range of aesthetics. In addition, many of these salt tolerant plants are native and so add cultural value to a property. In

this project, individual plant lists were created for each residential scenario based on the plants' specific resiliencies towards salt, soil moisture, sunlight, and wind. On a geospatial level, the plant lists change considerably as the distance from the coast increases: close to the coast, plant lists are dominated by highly salt-tolerant plants and further away they are dominated by moderately salt-tolerant plants. With regard to residency scenarios, the main difference governing plant options is different levels of environmental maintenance. In general, neighborhoods and apartment complexes experience lower levels of maintenance because they are either owned by an outside party and temporarily rented out (apartment complexes) – or not owned by anyone (neighborhood). In contrast, residents of individual homes and duplexes have the opportunity to develop their landscapes as they see fit. In all scenarios, however, there are ways to bolster the land and protect residents.

The designs in this project show that Savannah and other coastal cities facing similar challenges can very well adapt to the ever-changing climate –not by resisting it, but by adapting to it. In creating appropriate land uses and design management practices that are more resilient to climate change, Savannah residents will be able to continue to enjoy the unique outdoor aesthetic and, lifestyle benefits of their coastal city.

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APPENDIX A:
PLANT LIST - TREES

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Trees (Evergreen)	Magnolia grandiflora	Southern Magnolia	Medium	60'-80' x 30'-50'	Full Sun to Partial Shade	1	1
	Sabal palmetto	Cabbage Palm	Low	50' x 70'	Full Sun to Partial Shade	1	2
Trees (Deciduous)	Amelanchier arborea	Common Serviceberry	Low	15'-25' x 15'-25'	Full Sun to Partial Shade	2	1
	Carya tomentosa	Mockernut Hickory	Low	60'-80' x 40'-60'	Full Sun to Partial Shade	1	2
	Celtis laevigata	Sugarberry	Low	60'-80' x 60'-80'	Full Sun to Partial Shade	2	2
Normal to Well Drained Soil							
Trees (Evergreen)	Juniperus virginiana	Eastern Red Cedar	Low	30'-65' x 8'-25'	Full Sun	1	1
	Sideroxylon tenax	Tough Bully	Low to Medium	12'-30' x 20'	Full Sun to Partial Shade	1	1
Trees (Deciduous)							
	Fagus grandifolia	American Beech	Low	50'-80' x 40'-80'	Full Sun to Partial Shade	1	1
	Gleditsia triacanthos	Thornless Honey Locust	Medium	60'-80' x 60'-80'	Full Sun	2	2
	Quercus chapmanii	Chapman's Oak	Medium	15'-25' x	Full Sun	1	1
	Quercus geminata	Sand Live Oak	Low	30' x 40'	Full Sun to Partial Shade	2	1
	Quercus virginiana	Live Oak	Low	40'-80' x 60'-100'	Full Sun	2	1
	Zanthoxylum clava-hercul	Southern Prickly Ash	Low	15'-30' x 10'-25'	Full Sun to Partial Shade	1	1

APPENDIX B:
PLANT LIST - SHRUBS

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Shrubs (Evergreen)	Morella cerifera	Wax Myrtle	Low	10'-15' x 8'-10'	Full Sun to Partial Shade	2	2
	Myrcianthes fragrans	Simpson's Stopper	Low	6' x 8'	Full Sun to Partial Shade	2	2
Shrubs (Deciduous)	Callicarpa americana	American Beauty Berry	Medium	3'-6' x 3'-6'	Full Sun to Partial Shade	2	2
Normal to Well Drained Soil							
Shrubs (Evergreen)	Baccharis halimifolia	Eastern Baccharis	Low	10' x 5'	Full Sun to Partial Shade	2	1
	Ilex vomitoria	Yaupon Holly	Medium	10'-20' x 8'-12'	Full Sun to Partial Shade	2	1
	Serenoa repens	Saw Palmetto	Low	7' x 7'	Full Sun to Partial Shade	2	2
	Yucca filamentosa	Adam's Needle	Low	4'-8' x 2'-3'	Full Sun	1	2

APPENDIX C:
PLANT LIST - PERENNIALS

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Perennials	Baptisia australis	False Indigo	Low	3'x3'	Full Sun	1	1
	Heliotropium curassavicum	Seaside Heliotrope	Low		Full Sun to Partial Shade	1	2
	Limonium carolinianum	Sea Lavender	Low	2'-3' x 3'-5'	Full Sun	2	2
	Pontederia cordata	Pickerel Weed	Medium	2'-4' x 1.5'-2'	Full Sun	2	1
	Sabatia dodecandra	Marsh Rose Gentian	Medium		Full Sun to Partial Shade	1	2
Normal to Well Drained Soil							
Perennials	Helianthus debilis	Dune Sunflower	Medium	8'-10' x 1'-3'	Full Sun	1	1
	Solidago sempervirens	Seaside Goldenrod	Low	3' x 6'	Full Sun	2	1
	Baptisa 'Carolina Moonlight'	Carolina Moonlight False Indigo	Low	3'-4' x 3'-4'	Full Sun to Partial Shade	1	1

APPENDIX D:
PLANT LIST - GRASSES

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Shrubs (Evergreen)	Morella cerifera	Wax Myrtle	Low	10'-15' x 8'-10'	Full Sun to Partial Shade	2	2
	Myrcianthes fragrans	Simpson's Stopper	Low	6' x 8'	Full Sun to Partial Shade	2	2
Shrubs (Deciduous)	Callicarpa americana	American Beauty Berry	Medium	3'-6' x 3'-6'	Full Sun to Partial Shade	2	2
Normal to Well Drained Soil							
Shrubs (Evergreen)	Baccharis halimifolia	Eastern Baccharis	Low	10' x 5'	Full Sun to Partial Shade	2	1
	Ilex vomitoria	Yaupon Holly	Medium	10'-20' x 8'-12'	Full Sun to Partial Shade	2	1
	Serenoa repens	Saw Palmetto	Low	7' x 7'	Full Sun to Partial Shade	2	2
	Yucca filamentosa	Adam's Needle	Low	4'-8' x 2'-3'	Full Sun	1	2

APPENDIX E:
PLANT LIST -FERNS

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Perennials	Baptisia australis	False Indigo	Low	3'x3'	Full Sun	1	1
	Heliotropium curassavicum	Seaside Heliotrope	Low		Full Sun to Partial Shade	1	2
	Limonium carolinianum	Sea Lavender	Low	2'-3' x 3'-5'	Full Sun	2	2
	Pontederia cordata	Pickerel Weed	Medium	2'-4' x 1.5'-2'	Full Sun	2	1
	Sabatia dodecandra	Marsh Rose Gentian	Medium		Full Sun to Partial Shade	1	2
Normal to Well Drained Soil							
Perennials	Helianthus debilis	Dune Sunflower	Medium	8'-10' x 1'-3'	Full Sun	1	1
	Solidago sempervirens	Seaside Goldenrod	Low	3' x 6'	Full Sun	2	1
	Baptisa 'Carolina Moonlight'	Carolina Moonlight False Indigo	Low	3'-4' x 3'-4'	Full Sun to Partial Shade	1	1

APPENDIX F:
PLANT LIST - VINES

	Botanical Name	Common Name	Maintenance	Height x Width	Sun Exposure	Salt Tolerant	Wind Resistant
Normal to Moist Soil							
Vines (Deciduous)	Ipomoea sagittata	Saltmarsh morning-glory	Low	3' x 4'	Full Sun	2	2
Normal to Well Drained Soil							
Vines (Deciduous)	Ampelopsis arborea	Peppervine	Low	12' - 15'	Full Sun to Partial Shade	1	1
	Passiflora incarnata	Purple Passionflower	Low	12' - 25'	Full Sun to Partial Shade	1	1