Long-term planning for coastal wetland habitat restoration along the Gulf Coast region

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Table of Contents

Color Key:

Blue= Karen Vyverberg

Green= Nick Vitale

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Black= jointly authored

Executive Summary

This Report is the product of the second interdisciplinary working group from the Sea Level Rise and Coastal Ecology: Science, Policy, and Practice course at the University of Florida. In this document, we present the results of scientific and legal research, field work, and stakeholder engagement on short-term and long-term planning for coastal wetland habitat restoration along the Gulf Coast region of Florida.

This work was motivated by increasingly extreme coastal ecosystem changes caused by changes in regional climate affecting the local wetland habitat and human residents in the Gulf Coast region of Florida. Shifting ecosystem communities and shoreline erosion events highlight the need for strategic planning strategies to sustainably manage coastal resources and human populations for the short-term and long-term future.

We present an analysis of climate change impacts critical to the Big Bend Region of Florida and evaluate their effects on the coastal ecosystems and communities in the context of the regional geologic setting. Specifically, we evaluate the replacement of *Spartina* saltmarsh with mangrove trees due to rising temperatures, and the effects on shoreline stabilization and sediment transport. We then evaluate the current policies regarding coastal property law and mangrove management and propose strategic recommendations in a variety of management styles and time-frames.

Key Messages

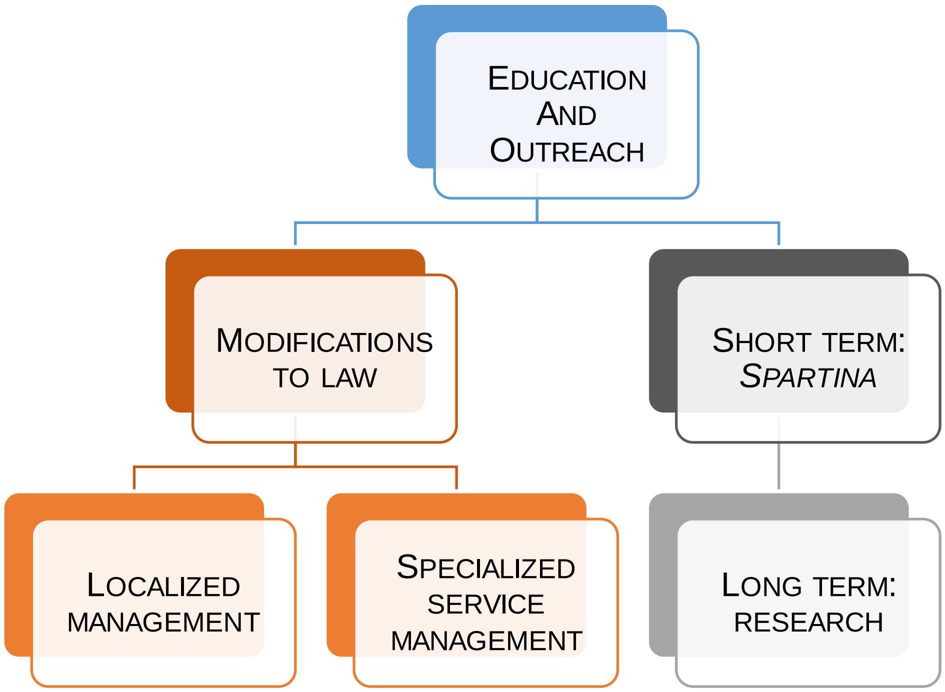
1. The regional climate is changing in accordance with shifts in the global climate system. Local sea-level is rising; temperatures are increasing; the number of cold days is decreasing; and hurricanes are intensifying.
2. Rising sea-level and impacts from storm events are exacerbating coastal sediment erosion.
3. Shifts in regional temperature regimes are responsible for the replacement of *Spartina* salt marsh by mangroves.
4. Planned restoration efforts must account for the short-term and long-term ecological characteristics of both plant groups.
5. Current policy on mangrove management is restrictive because mangroves are protected by state law.
6. A coastal wetland management plan designed to combat erosion in the face of climate change requires a multi-faceted approach.

Key Policy Recommendations

1. Continued outreach and increased education to promote legal and ecologically safe trimming of mangroves with an understanding of their ecological benefits.
2. Modification, reinterpretation, and/or reapplication of existing mangrove law for more localized management control and specialized service management.
3. Short-term shoreline restoration using *Spartina* saltmarsh for rapid sediment stabilization.
4. Long-term research plan to investigate the impact of sudden mangrove forest die-offs on coastal ecosystems.

We argue there is a high degree of certainty that the climate conditions in the Big Bend will continue to favor the replacement of *Spartina* salt marsh by mangrove forest. Coastal erosion

will be increasingly likely in the face of sea-level rise and intensifying hurricanes, necessitating a short-term and long-term adaptation strategy. Therefore, we propose three short-term policy recommendations, and call for increased research into the long-term effects of rapid ecosystem shifts on the Big Bend coastal wetlands. This multi-faceted approach is illustrated below schematically.



1. Introduction

Coastal ecosystems and communities currently face a growing set of challenges as they adapt to the effects of climate change. Globally, about 10% of the world’s population lives less than ten meters above sea level and thus vulnerable to a number of social and economic threats as the result of climate change (McGranahan et al., 2007). In the U.S., 30% of the population resides in coastal counties susceptible to the effects of climate change (Crowell et al., 2007). This number is expected to increase as the population itself grows, and as residents move disproportionately into coastal communities (Crosset et al., 2013). Coastal areas provide a large number of ecosystem services to the human populations they support including commercial and recreational fisheries, water filtration and purification, and flood protection (Barbier et al., 2011). Accelerating sea-level rise alone is in direct contention with the increasing demand for coastal residential land use. The superposition of this threat with other impacts from climate change such as rising temperatures and increased storm intensity necessitate action for vulnerable coastal communities. In this Report, we examine the combined effects of sea-level rise and shifting species distributions on coastal ecosystems and residents in Florida’s Gulf Coast (Fig. 1), and investigate the potential management and adaptation strategies available to these communities within a legal framework.

Figure 1. Modified from *Williams et al., 1999*. Map of the Big Bend Region of Florida. Locales mentioned in the text are denoted with a white star. Inset is the state of Florida, including the Gulf Coast, with the Big Bend highlighted in red.

The Big Bend region of Florida (Fig. 1) is a unique landscape renowned for its marshy coastline and productive fisheries. With relatively small tidal fluctuations (less than 0.5 m), the coastal landscape is frequently changing in response to storm events. The Big Bend Region of Florida is characterized by low wave-energy and small sediment supplies (Morton et al., 2004). This low energy and sediment supply combine to give the Big Bend region a low topographical gradient, making it very susceptible to inundation from sea-level rise or storm activity. Additionally, because there is not a large, constant supply of sediment, erosion events will result in shoreline loss or redistribution, but shoreline progradation, which would help combat sea-level rise and storm energy, is limited to nonexistent. Therefore, this coastline is highly vulnerable to the effects of sea-level rise and climate change, and is heavily dependent on coastal wetlands for shoreline retention.

Coastal wetland habitat protection and restoration has become an important topic in the face of sea level rise and climate change. Vegetated coastal habitats are considered one of the most valuable ecosystem types, for both humans and the environment (Costanza et al. 1997) because of many critical ecosystem services they deliver, including coastal community protection through energy breaks and erosion prevention, nutrient uptake, providing fisheries and wildlife habitat and high rates of carbon sequestration.

Two coastal wetland plants dominate in the Big Bend: *Spartina* saltmarsh and mangroves. Mangroves and saltmarsh, generally, are separated in geological distribution by a temperature-related threshold, which limits their range. Near these thresholds, mangrove-saltmarsh ecotones occur (Osland, et al 2013). As climate changes, these areas of overlap shift. The Big Bend region encompasses this mangrove-saltmarsh ecotone; however, in recent years climate changes have created an increase in the number of mangroves and a subsequent loss of *Spartina* salt marsh. This makes deciding how to protect and restore coastal habitats a difficult task, especially in the face of continuously shifting local climate conditions. The mechanisms that favor saltmarsh or mangrove development on short and long time scales need to be considered for protection and restoration efforts.

Mangroves are currently protected by the Mangrove Trimming and Preservation Act of 1996.[i] This Act prohibits the cutting or removal of mangrove trees without a permit from the state, but allows for certain trimming of mangroves in order to maintain a property owner's riparian right of view.[ii] The Legislature adopted this Act based on their findings of how vital mangroves are as habitat to myriad wildlife, as shoreline stabilizers and protection from storms, and for water quality protection and food-web support, including nursery support to commercial fisheries.[iii] The Legislature found that the ecosystem services provided by mangroves also benefit the economies of coastal communities.[iv] The Legislature passed the Act explicitly to "protect and preserve mangrove resources valuable to our environment and economy from unregulated removal, defoliation, and destruction."[v] But at the same time, the Act was written in a way to promote the rights of waterfront property owners, and further, to encourage waterfront property owners to voluntarily plant and maintain mangroves.[vi] The Florida Department of Environmental Protection upholds its commitment to a riparian property owner's right to view by promoting various horticulture techniques for trimming mangroves within the boundaries of the Act.[vii]

Floridians often have a love-hate relationship with mangroves. Mangroves contribute to the ecological character of the state, and many Floridians appreciate their uniqueness. Still, many Floridians hold disdain for the trees because of their tendency to block pricey waterfront views. The Act seeks to strike a balance between preserving the mangroves for their large environmental value and allowing homeowners to maintain their view. Even with the freedom to style mangroves down to their legal height, homeowners frequently clash with these trees. The Act dictates strict procedure one must go through if they wish to remove mangroves, and even then, it may not be approved. The Act generally does not account for local environmental differences. The needs and concerns of locals go largely unheard. A local government can receive delegation from the state to regulate mangroves, but this section of the Act is underutilized. As mangroves move into areas where they have not been as historically prevalent, locals who have not had to deal with the Act in the past get frustrated with its stringency. As the climate continues to change and mangroves continue to spread, this conflict will spread, as well.

In this Report, we evaluate the climatic state of the Big Bend region in the context of wetland habitat restoration for coastal ecosystem services and provide a legal analysis of the current regulations regarding coastal ecosystem management. As the local plant community shifts with progressive changes in local climate, we propose that new coastal management techniques need to be implemented within the confines of the current law and recommend a four-tier adaptation strategy that 1) builds on community education and engagement, 2) improves existing mangrove management laws, 3) utilizes short-term restoration techniques, and 4) includes a long-term research and data-gathering plan to evaluate the need for subsequent policy on coastal wetland management.

2. Issue Analysis

2.1 Climate Change and Florida's Gulf Coast

Since 1988, the international scientific community has generated regular consensus reports based on peer-reviewed publications on the state of our knowledge on climate change including observations of trends, causal links, and predictions for the future. The latest of these reports, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) details observational evidence for anthropogenic (human-caused) climate change, its current impacts on global and regional climate, and projections of future climate change (IPCC, 2014). Independent, U.S. government agencies have detailed similar reports on climate change in the U.S. at the national, regional, and local level (Morton et al., 2004; Crosset et al., 2013; Walsh et al., 2014). The impacts from climate change, particularly rising sea levels, changes in storm intensity, shifts in annual weather patterns, and increasing air temperatures are all currently felt, or will be felt, along Florida's Gulf Coast. The regional geology leaves the area particularly susceptible to these specific impacts; therefore, understanding the nature of these changes, as well as the timing and magnitude of projected ecosystem shifts in response, are all critical to the strategic adaptation and management of the Big Bend region for local communities in the future. In this Section, we provide an overview of the current knowledge of global climate change, including observations and predictions (2.1.1); an overview of the regional effects of global climate change, observations, and projections for the future (2.1.2); and examine these global and regional scale effects from climate change in the context of the unique coastal system of the Big Bend of Florida (2.1.3).

2.1.1 Changing Global Climate

While the effects of climate change are far-reaching and numerous, a subset of processes are particularly relevant for Florida's Gulf Coast and are focused on here in this Report. The first major impact from climate change important in the Big Bend is increasing temperature. Observational evidence from *in situ* and satellite measurements show that global temperature (the land and ocean average) has increased by 0.85 °C from 1880-2012 (IPCC, 2014). Superimposed on this overall increase are multi-decadal and interannual temperature variations such as the El Niño cycle. However, the overall warming trend is larger than the variability in these natural, short-term cycles, is statistically significant, and is observed across a multitude of components of the climate. Additionally, brief warm events prior to industrialization (1765) like the Medieval Warm Period do not show a regional coherence like late-20th century warming does (IPCC, 2014). Over the next few decades (2016-2035) the IPCC (2014) predicts that global mean surface temperatures will continue to increase relative to the past two decades (1986-2005) by 0.3 to 0.7 °C.

Changes in seasonal and annual weather events are more challenging to quantify, but several trends are clear in the 2013 IPCC AR5. Changes in extreme weather and climate events have been observed since 1950. Globally, the number of cold days and nights has decreased, while the number of warm days and nights has increased (Bindoff et al, 2013). The intensity and frequency of daily temperature extremes are particularly critical to coastal floral species distributions in the Big Bend region (Section 2.2). There is strong evidence for anthropogenic forcing on these changes in extreme temperatures (Bindoff et al., 2013). An increase in atmospheric temperature results in the capacity for more moisture to be held in the atmosphere. In fact, a general increase in heavy precipitation globally has been observed, but its direct causal link to anthropogenic forcing is not yet confirmed (Bindoff et al., 2013). However, in North America there is evidence for a statistically significant correlation between an increase in winter precipitation and an increase in atmospheric moisture content (Wang and Zhang, 2008). Changes in cyclone (hurricane) patterns are also hard to quantify, but the intensity of tropical hurricanes is directly related to the temperature of the sea-surface in the tropics. Some studies show a direct correlation between recent increasingly intense hurricane activity and sea-surface temperature (SST) increases (Elsner, 2006; Emanuel, 2005). However, while the intensity of hurricanes may increase, there is limited evidence suggesting the number of storms has increased since industrialization and the direct attribution of specific extreme weather events to anthropogenic impacts on global climate remains challenging (Bindoff et al., 2013).

Finally, patterns of rising global mean sea level (GMSL) have been quantified and largely attributed to global warming. GMSL has increased by 0.19 m from 1901-2012, and the rate of rise has accelerated since the latter half of the 20th century (IPCC, 2014). Satellite altimetry and tide gauge data both support this observation. While the overall rate of GMSL rise from 1901-1990 was 1.2 ± 0.2 mm/year, the rate increased to 3.0 ± 0.7 mm/year between 1993 and 2010 (Hay et al., 2015). Most of this increase in GMSL is the result of thermal expansion and melting mountain glaciers (Church et al., 2011). Increasing the amount of heat stored in the oceans results in an expansion of the ocean volume, and thus an increase in GMSL. Additionally, the largest sources of new water to the oceans throughout the 20th century have been from the melting of mountain glaciers. However, as global temperatures continue to rise, an increasingly large fraction of GMSL change will be from the continental ice sheets in Greenland and Antarctica (Bindoff et al., 2013). Geological context is important in the discussion of rising GMSL. Recent work has shown that during the previous warm period (~125,000 years ago), global SST's were essentially indistinguishable from the global average SST's between 1995-2014 (Hoffman et al., 2017). Global mean temperatures may have been ~1°C relative to pre-industrial (Dutton et al., 2015) and as discussed above, current observations have reported a global temperature increase of 0.85 °C since pre-industrial (IPCC, 2014). During this same time period, however, GMSL was at least 6 m above present-day levels due to large contributions of meltwater from Greenland and Antarctica (Dutton et al., 2015). This observation suggests that as the global climate system comes into equilibrium with current global temperature and SST increases, the associated increase in GMSL could be large.

2.1.2 Regional Climate Change: Observations and Predictions

The global trends in temperature, seasonality, and sea level described above are observed on regional scales as well in the United States and on Florida's Gulf Coast. A number of U.S. entities have recorded these trends in published literature like the National Climate Assessment (2014) and NOAA's (National Oceanic and Atmospheric Administration) State of the Coast

(2013). In the U.S., average temperature has increased by 0.7 – 1 °C (1.3 – 1.9 °F) since 1895, and the majority of the temperature increase has occurred in the last four decades (Fig. 2) (Walsh, et al., 2014). Moreover, temperature is expected to continue to increase over time, but in a spatially variable pattern and in addition to natural climate variations and cycles. In the U.S., 2012 was the warmest year on record. Additionally, the U.S. is expected to be on par with the rest of the world for continued increases in average temperatures with time (Walsh, et al., 2014).

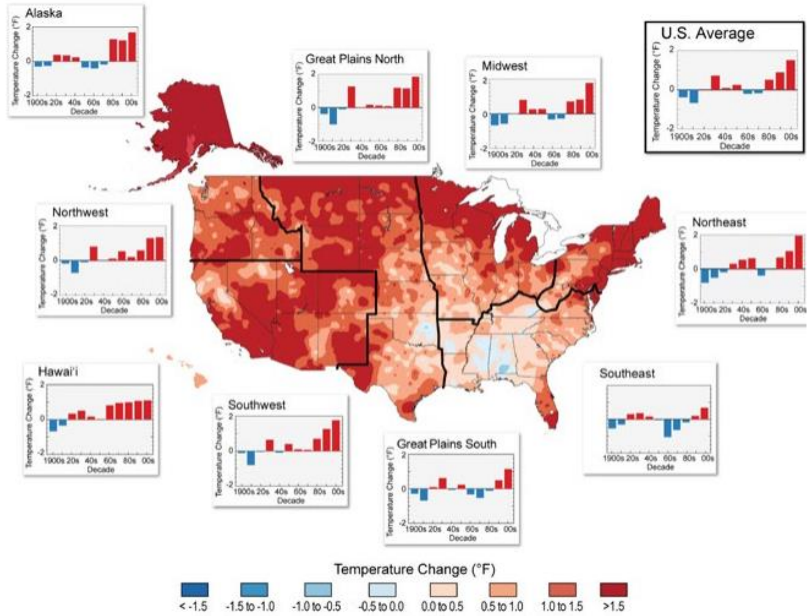


Figure 2. *Walsh et al., 2014.* Observed temperature changes in the U.S. Map colors show temperature changes from 1991-2012 relative to 1901-1960. Inset bar graphs show the average temperature changes for each region. In every region, the most recent period from 2001-2012 was the warmest on record.

National and regional changes in seasonality have also been observed, and are predicted to continue into the future. Nationally, the number of frost-free days each year has been increasing since the 1980's (Fig. 3) (Walsh, et al., 2014). The length of the frost-free season (the number of days between the last freeze in the spring and the first freeze in the fall) is a large determinant of plant distributions, which is particularly important in the Big Bend region (Section 2.2). Since the 1980's, the length of the frost-free season in Florida has increased by 6 days (Walsh, et al., 2014). While the length of the frost-free season in the U.S. is expected to increase with increasing greenhouse gas emissions, the Southeast U.S. will actually see the smallest increase in the length of the frost-free season. However, it is projected that the southern boundary of the seasonal freeze zone will move northward overall, with larger numbers of years without sub-freezing temperatures in the southern-most areas of the U.S. (Walsh, et al., 2014). Changes in U.S. precipitation are also similar to global trends, with an overall increase in precipitation in most areas. The Gulf Coast region of Florida, however, has seen a slight decrease in annual precipitation by ~5% (Walsh, et al., 2014). Seasonal precipitation trends are also expected to shift, with a decrease in winter, spring, and summer precipitation along Florida's Gulf Coast by ~10-20%, while fall precipitation is predicted to increase by ~20% (Walsh, et al., 2014). While seasonal precipitation may decrease for the Gulf Coast, overall extreme precipitation events have been increasing in the Southeast and in the U.S. overall since 1991 (Walsh, et al., 2014). In the Southeast, this increasing trend is statistically significantly larger than natural variations. Similar to global trends in the number of cold days/nights and warm days/nights, in the U.S. the number of extreme cold events has reached the lowest levels ever recorded (since 1895) and the number of record-high temperatures continues to increase (Walsh,

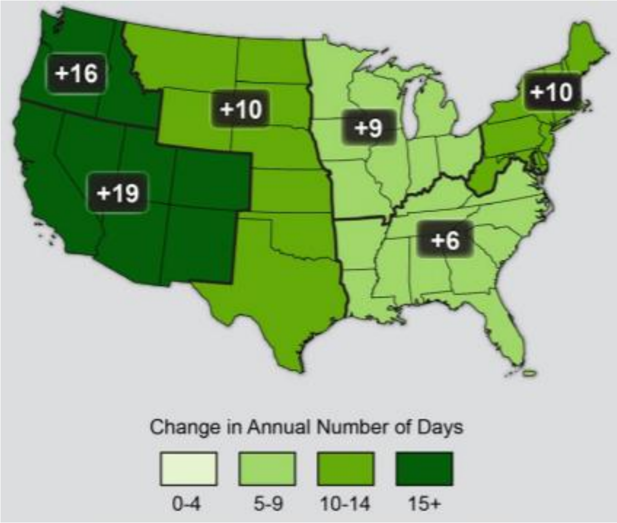


Figure 3. *Walsh et al., 2014.* Overall increases in the frost-free season length in six different regions of the U.S. The frost-free season length is the number of days between the last freezing temperature (0°C) in Spring and the first freezing temperature occurrence in Fall. Here, changes are for 1991-2012 relative to 1901-1960. Increases in the frost-free season length are critical for freeze-sensitive plant species, like mangroves, to establish and grow.

et al., 2014). These trends are, again, expected to continue into the next century with unchecked greenhouse gas emissions. Along Florida's Gulf Coast, the temperature of the coldest days is projected to increase by 6 – 8 °F by the year 2100 (Walsh, et al., 2014). Finally, the U.S. analysis shows an increase in the number and power of North Atlantic hurricanes since the early 1980's, and in winter storms since the 1950's (Walsh, et al., 2014). While the National Climate Assessment reports an increase in the number of Category 4 and 5 hurricanes in the North Atlantic, a major hurricane (Category 3-5) has not made landfall in Florida since 2005. In September of 2016 a Category 1 hurricane did make landfall along Florida's Big Bend coast, but statistically it is only a matter of time before another major hurricane makes landfall in Florida.

Changes in regional or local sea level (RSL) are spatially variable and can differ from GMSL for a number of reasons (local tectonic activity, land use changes, glacial rebound etc.). In the Southeastern U.S., RSL changes are about 20% larger than GMSL changes due to factors like glacial rebound and local subsidence (Mitchum, 2011). At the current rate of sea-level rise, the Southeastern U.S. could likely see about 1 m in sea-level rise by the year 2100. In Cedar Key specifically, the local tide gauge has recorded an increase of about 20 cm in sea-level since 1914 (Fig. 4). The mean sea level trend is 1.97 millimeters/year with a 95% confidence interval of ± 0.18 mm/yr based on

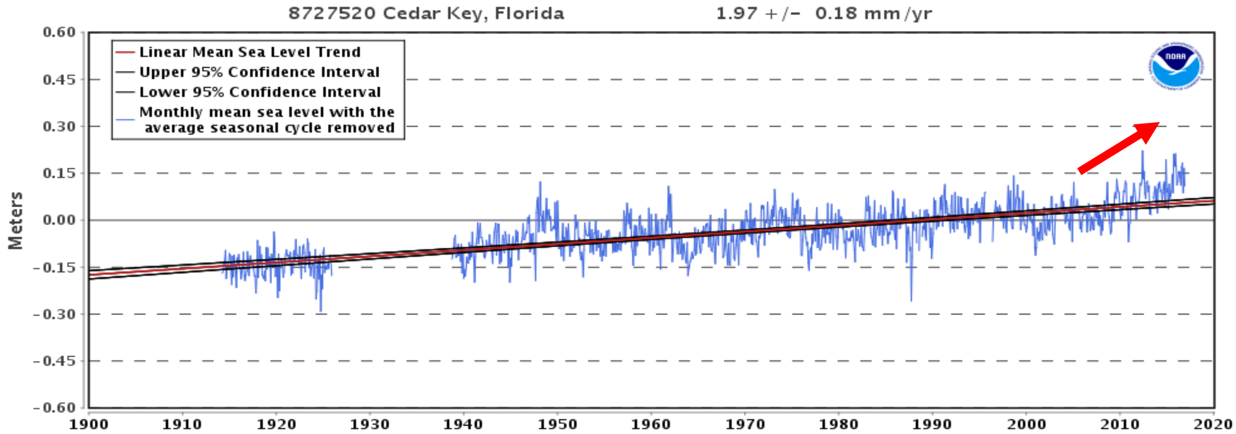


Figure 4. NOAA Cedar Key, Florida tide gauge record from 1914-2017. RSL in Cedar Key, Florida has increased over last 103 years. This increase represents the superposition of glacial adjustment, thermal expansion, and increased water volume from melting mountain glaciers and continental ice sheets. The rate of rise was steady from 1914 to ~2009 when an acceleration is clear (red arrow).

monthly mean sea level data from 1914 to 2015. However, since 2000, the rate of sea-level rise has accelerated, with Cedar Key experiencing an increase in RSL of 15 cm. Sea-level rise is a critical and unique effect of climate change in that it is virtually certain to continue to rise with time. Moreover, the majority of estimates of future sea-level rise are conservative estimates because they do not include contributions from the Antarctic Ice Sheet, which may be extremely susceptible to rising ocean and air temperatures, but is hard to model (Church et al., 2013).

2.1.3 Context: Unique Local Geologic Setting

A comprehensive understanding of the effects of climate change on Florida's Gulf Coast is incomplete without the context of the regional geologic setting. The ways in which changes in local temperature, sea level, and seasonality act on this unique coastline is dependent on the local geology. Indeed, a large focus of this Report is combatting erosion along Florida's Big Bend and the physical characteristics of this area's coastline largely determine the type and trend of shoreline change (Morton et al., 2004). The present-day coastline morphology was generated when sea-level was much lower than today (by about 130 m) which allowed coastal rivers to carve valleys along the continental shelf during the last glacial period (~20,000 years ago) and deposit fluvial sands (Morton et al., 2004) which form the main portion of modern off-shore shoals (Wright et al., 2005). Around 4000 years ago, though, deglacial RSL rise slowed, sediment input to the Suwannee River increased, and so coastal sedimentation increased (Wright et al., 2005). These relict sediments are the main components of the modern shoreline, which has a very low topographic gradient.

Today, the Suwannee River is partially spring-fed and has its only sediment source in the coastal plains of Georgia (Wright et al., 2005). The Suwannee River is the main sediment source for the Big Bend area because the Waccasassa River, which also flows into the Big Bend region of the Gulf of Mexico, is considered to have insignificant sediment input during normal flow conditions (Wood and Hine, 2007). Overall, this region is sediment-starved, low-energy, low-gradient, and dominated by marshes and tidal creeks (Wood and Hine, 2007; Wright et al., 2005). Most shoreline sedimentation occurs as reworking of present sediments by tidal creeks in the absence of storms (Wood and Hine, 2007). However, the largest increases in coastal sediment occur during large storm events when offshore sediments are deposited inland (Morton et al., 2004). These storms can exacerbate erosion, however, as well and are not a viable, natural solution to shoreline erosion. In the late nineteenth century, the island of Atsena Otie Key was a thriving lumber and fishing community. Less than 1 km south of Cedar Key, the town on Atsena Otie Key was wiped out during the 1896 Cedar Keys Hurricane, and abandoned by the community in favor of Cedar Key shortly thereafter (Oickle, 2009).

2.2 Local Marsh Community and Options for Restoration

2.2.1 *Spartina* Salt Marsh

Spartina salt marsh is the dominant coastal marsh vegetation type outside of the range of mangroves. There are numerous *Spartina* species, *Spartina alterniflora* being the most abundant in the Cedar Key area. *Spartina* is a grass that grows in intertidal wetlands (from mean sea level to the high high tide line) and can survive in high salinity areas. Growth and reproduction does slow with increasing salinity (Fig. 5) and *Spartina* is typically out-competed in completely fresh systems. Therefore, *Spartina* does best in estuarine conditions. *Spartina* responds rapidly to disturbance events such as fire or storms, quickly becoming established in these newly available areas. Fire is an important factor in the ecology of gulf coast marshes. Year-round growth by salt marsh plants results in a system very susceptible to fire within 3-4 years.

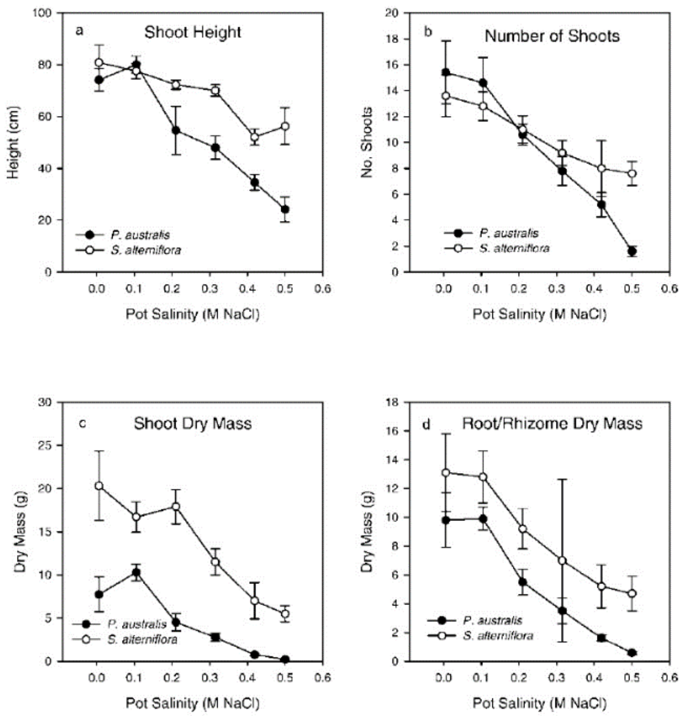


Figure 5. *Vasquez et al. 2006*. Effect of salinity on (a) shoot height, (b) number of shoots, (c) shoot dry mass, and (d) rhizome + root dry mass produced by *Phragmites australis* and *Spartina alterniflora* in a salt tolerance experiment. Error bars are standard errors of means.

2.2.2 Mangroves

Mangroves are a tropical tree species that, like *Spartina*, specialize in saline environments. There are three species in Florida—Red (*Rhizophora mangle*) Black (*Avicennia germinans*) and White (*Conocarpus racemose*)—all of which have become established within the Big Bend of Florida. Black mangroves are the most abundant in the Big Bend partially due to being more tolerant of cold temperatures than the other two species. Trees can either have the ability to survive freezing temperatures or handle living in salt water, but there are no known examples of trees which can do both. Therefore, mangrove trees are freeze intolerant and limited to tropical environments. How susceptible mangroves are to dying from freezing temperatures depends on many factors, including the duration which sub-freezing temperatures persist, weather conditions leading up to freezing event, size, and location of tree. However, recent studies suggest -4°C as the threshold temperature for mangrove freeze tolerance (Cavanaugh et al. 2014). As freeze events occur less frequently mangroves are becoming established further north as well as increasing in abundance in many areas (Fig. 6). Also, like *Spartina*, mangroves grow in the same intertidal zone. However, because they have pneumatophores, which allow for gas exchange to the roots and help with stabilization in soft sediments, mangroves can survive in a slightly wider range of elevations.

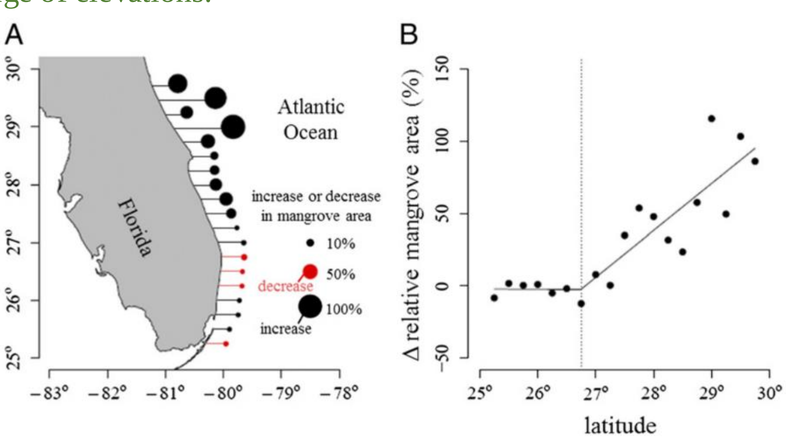


Figure 6. *Cavanaugh et al. 2014*. (A) Map showing increase (black) or decrease (red) in mangrove area for each 0.25° latitudinal band. (B) Relationship between latitude and relative change in mangrove area. Solid line represents a piecewise regression and the vertical dotted line gives the breakpoint (26.75°N) of the piecewise regression.

2.2.3 Coastal Wetland Ecosystem Services

One important role of coastal species such as *Spartina* and mangroves is their ability to stabilize shorelines as well as accrete sediments. As sea levels rise, this ability to accrete sediments has become more important in the maintenance of coastlines. Rates of accretion vary widely between areas. *Spartina* typically accretes 3-5mm of sediment per year (Ranwell, 1964), and because of its rapid growth in newly disturbed areas, *Spartina* can begin providing this ecosystem service more rapidly than mangroves. Mangroves typically have lower accretion rates at ranging from 0.2-2mm per year (Jimenez et al. 1985). However, sediment coring has shown that mangroves may be better at holding sediments over the long term. This is likely related to mangroves producing a larger volume of roots over a greater range of depths as well as having more aboveground structure compared to salt marsh plants (Comeaux et al. 2012; Duarte et al. 2013). As outlined in section 2.1, within the Big Bend, most sediment accretion occurs during storm events. Therefore, exact accretion rates and ability to keep up with sea level rise will depend on these storms as much as coastal vegetation.

In many areas, large storm events are responsible for rapid and significant sediment accretion. Therefore, the ability of these plants to withstand and recover from storms plays an important role in how well new sediments are stabilized and retained after these events. Both *Spartina* and mangroves are adapted to these types of events. Strong winds and waves are more likely to damage mangroves through breaking limbs as well as uprooting. Storm damage rarely kills mangroves; though, areas where trees have been uprooted may see destabilization of sediments. In addition, rapid accretion of sediment around black mangroves can kill the tree if the pneumatophores are buried. The pneumatophores are responsible for gas exchange to the root system, and therefore, when they are buried they can no longer perform this function, which results in the root system suffocating (Ellison 1999). *Spartina* may become entirely buried by sediment deposition from a storm, but due to its ability to rapidly become reestablished, *Spartina* salt marsh is generally less impacted by storm events than mangroves. As climate change occurs and tropical storms become more intense these variables are becoming more important.

Despite generally warmer temperatures associated with climate change, freezing temperatures will continue to occur within the Big Bend. Therefore, mangroves within this region will still suffer die offs from freeze events. Once dead, mangroves can still retain sediment for 3-5 years after death (Jimenez et al. 1985). During this time, new vegetation will be able to become established before rapid sediment erosion begins to happen. However, following a mangrove die off, rates of sediment erosion can increase (Jimenez et al. 1985). In addition, to potential losses of sediment retention, die offs of mangroves may have other impacts on the local ecosystem. A sudden defoliation of a large area of mangroves may result in a large pulse of nutrients being delivered into the water. This sudden nutrient load could have significant impacts on water quality, influencing a wide range of fish and wildlife species including economically important fisheries. This defoliation also means a sudden loss of cover and other habitat services utilized by many species of fish and wildlife. Finally, mangroves play an important role in the take up of nutrients and carbon from the water and air and when they die, this vital service obviously ceases.

Coastal wetlands play an important role in sequestering carbon from the environment and trapping it in living biomass and sediments (McLeod et al. 2011). Salt marshes have among the highest carbon storage per land area compared to other terrestrial systems. However, mangroves represent a disproportionately large contribution to global wetland carbon stores (Alongi 2014). Within the salt marsh-mangrove transition area of Florida, Doughty et al. (2015) found that mangroves have double the carbon trapped in sediments and biomass compared to salt marsh. This is likely in part due to the fact it has much more biomass than salt marsh plants. This represents the potential for a significant increase in wetland carbon storage where the system is transitioning from salt marsh to mangroves. The amount of increase in carbon storage as a product of mangrove range expansion in Florida is equivalent to 50% of the state's annual anthropogenic carbon emissions. Therefore, mangrove range expansion may play an important role in combating the very climate change which is causing their expansion.

Ecological benefits of both *Spartina* and mangrove habitats are extensive, and help support a wide range of plants and animals. *Spartina* is utilized by a variety of fish and wildlife species including West Indian manatees (*Trichechus manatus*), who use *Spartina* as a food source. Many species of birds and mammals use it for cover and habitat to forage in. Several species of passerine birds will use saltmarsh for nesting. *Spartina* supports large populations of periwinkles, which are an important food source for many fish species as well as diamondback terrapins (*Malaclemys terrapin*).

Mangrove forests create a very different habitat type than *Spartina*. For example, mangroves provide potential nesting habitat for seabirds and wading birds. Mangrove forests provide important nursery grounds for many fish species. Numerous tropical fish species rely on mangrove forests for at least a portion of their life cycle; therefore, mangrove range expansion may play a vital role in the expansion of tropical fish ranges as climate changes and ocean temperatures increase.

Interestingly, *Spartina* and mangroves provide habitat and foraging opportunity to many of the same species. For example, many important game fish species can be found utilizing both habitat types. Therefore, a shift from one habitat type to the other may not result in significant species changes within the ecosystem. However, a shift from a landscape of just salt marsh to just mangrove (or vice versa) would result in changes in abundance of some species and influence how many species utilize the area. A mix of both habitat types is probably best so fish and wildlife species can maximize benefits gained from either.

2.2.4 Wetland Restoration: *Spartina* and Mangroves

In the Big Bend, freshwater forests convert to salt marsh due to increased tidal flooding. This flooding provides favorable conditions for mangrove forests to become established. However, salt marsh becomes established first and a dense salt marsh plant community will suppress mangrove expansion. Mangroves' ability to move into new habitat relies greatly on propagule dispersal (Patterson et al., 1993 and Patterson et al., 1997) and subsequent establishment. Amy Langston (unpublished data) found 99% of mangrove propagules were lost due to predation by crabs within 10 days of placement across all landscape positions and sites tested within the Big Bend. This observation suggests that mangrove establishment is greatly reduced and potentially stopped due to vulnerability of propagules to predation. Mangroves have high phenotypic plasticity increasing their competitive ability over other native species (Davidson et al., 2011). Once established, mangrove seedlings grow rapidly and shade out other species including grasses like *Spartina*. Therefore, understanding mangrove seedling dynamics may be especially important for assessing future distributions in these important habitats.

Stevens et al. (2006) suggested a 20-30 year timeline for complete seedling cover to occur after a freeze under current conditions.

The Cedar Key area represents the northernmost extent of mangroves along the Gulf coast of Florida. This expansion combined with reduction in the frequency of freezing temperatures associated with climate change results in a period of transition in the salt marshes. Mangroves have long been part of the landscape around Cedar Key but in small numbers historically. Freezing temperatures kill mangroves and therefore suppress their northward expansion. The last major freeze event resulting in a major mangrove dieback occurred in 1989. Since that time, mangroves have become re-established and now occupy a significant portion of what was historically *Spartina* salt marsh.

When considering options for coastline restoration and revegetation projects there are many logistical considerations that must be taken into account. First, the cost with planting either mangroves or *Spartina* is an important factor in decision-making. Mangroves are much more expensive with costs ranging from $2500/ha for established seedlings spaced 1 m apart, to upwards of $200,000/ha for larger 3-year-old trees (Teas, 1977). Whereas planting *Spartina* is a fraction of the cost of mangroves due to lower per unit production costs, and lower transportation costs. In addition, there are significant differences in the actual planting effort required. Mangroves can be planted at a number of stages from seedlings up to a 3-year-old established tree. The larger sizes are much more labor intensive to plant, however fewer are needed compared to seedlings and they will have a high likelihood of successfully becoming established. *Spartina* requires more dense planting compared to mangroves. However, planting typically is less labor intensive and *Spartina* has very high rates of successful establishment and spreads quickly in favorable conditions. While these logistical factors are important to consider, in general they should not be the deciding factors in choosing what species to utilize for revegetation projects.

Mangroves and *Spartina* offer many of the same services to both humans and wildlife. However, they both clearly not equal, and considering which conditions and management goals favor each must be considered. As climate and subsequently mangrove distribution and abundance continue to change, the elements that favor one or the other are likely to change in importance. Therefore, both short and long term goals are equally important.

2.3 Existing Law and Policy

2.3.1 Existing Law on Coastal Land Ownership

Mangroves, *Spartina*, and their respective abilities to combat sea-level rise can affect legal property boundaries. Coastal landowners enjoy a set of rights known as riparian rights. The recognition of riparian rights can be traced as far back as 1827, in the landmark case *Tyler v. Wilkinson*.[viii] Early recognition described a riparian property owner's right to use the water, have access to the water, and the right to not have someone else divert the water.[ix] Ambulatory boundaries were addressed next, culminating in the (still governing) Supreme Court case *St. Clair County v. Lovingston*.[x] In that case, the Court held that the riparian right to future accretion was a vested property right, describing it as "an inherent and essential attribute to the original property."[xi] The Court likened accretion to a natural harvest from which the property owner may benefit. And likewise, the risk of erosion is tied to the natural property rights of the land. Just as a property line benefits from accretion, a property owner loses land when erosion causes a boundary line to shift. The Court explained, "[t]he owner takes the chances of injury and of benefit arising from the situation of the property. If there be a gradual loss, he must bear it; if a gradual gain, it is his."[xii]

Avulsion, on the other hand, does not cause a boundary line to shift. Avulsion is a more sudden shift in water boundaries, while accretion and erosion are gradual shifts over a long period of time. If avulsion results in the sudden inundation of property, the boundary line does not change and the property owner now owns the submerged land.[xiii] If avulsion results in the sudden gain of property, the property line does not change and the landowner does not gain rights to the newly-exposed land.[xiv] This causes more uncertainty in property lines, especially as the planet experiences the effects of climate change.[xv] Some effects, such as stronger storms, are likely to lead to avulsion events, which result in meandering and unclear property lines. More gradual effects, such as a steadily rising sea level, are likely to cause erosion, which gradually eats away at riparian owners' property.

These rights extend to Florida law, as well. Florida recognizes a riparian property owner's rights to accretion, access, an unobstructed view, use of the water, and many others.[xvi] Avulsion and erosion affect a Florida landowner's property in the same way, as well.[xvii] Navigable water in Florida is held by the state in trust for use by the public in an arrangement known as the public trust doctrine.[xviii] Land owned through the public trust doctrine includes the water, the submerged land underneath, and the shore waterward of the mean high tide line (private landowners can own the property landward of the mean high tide line).[xix] Thus, as land erodes, the public, through the trustee of the state, gains rights to previously-privately owned land. This could have huge legal implications as sea level rises and the climate changes. Massive amounts of privately-owned coastal land are at risk of being converted into public property through natural processes.

Salt marshes and shoreline plants have the natural potential to curb this phenomenon. They trap sediment, accrete land, prevent erosion, and can even limit avulsion effects.[xx] But property owners often forget about these long-term benefits, distracted by short-term effects on their other riparian rights, such as a right to view. Mangroves affect this right more than *Spartina* because of their height, but mangroves are protected by state law, while *Spartina* is not.

2.3.2 Existing Law on Mangroves

Mangroves are protected by the Mangrove Trimming and Preservation Act of 1996. The Mangrove Trimming and Preservation Act (the Act) prohibits the cutting or trimming of mangrove trees without a permit from the state of Florida.[xxi] The legislative intent of the Act is to "protect and preserve mangrove resources valuable to our environment and economy from unregulated removal, defoliation, and destruction."[xxii] Florida recognized the ecological importance of mangrove trees and passed this legislation to protect them.[xxiii] But keeping in mind homeowner autonomy and riparian right of view, the Act allows for several exemptions.[xxiv]

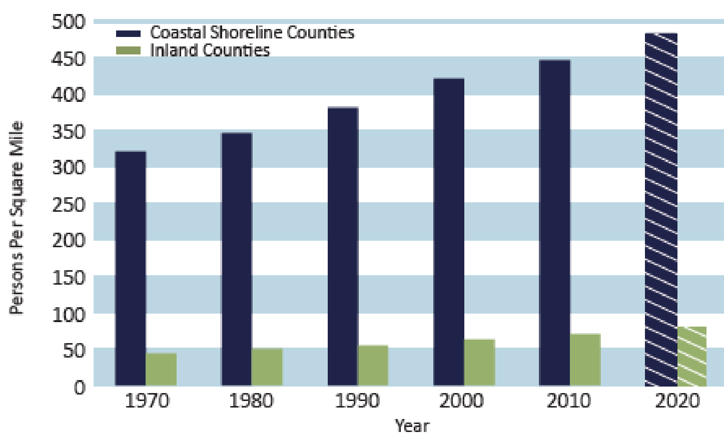
Riparian mangrove fringe property owners may trim their mangroves freely if they are less than ten feet in pretrimmed height.[xxv] Maintenance trimming of mangroves is also exempt from needing a permit.[xxvi] These two activities encompass most of the mangrove trimming done by the average homeowner. Beyond those, a general permit is required for a riparian property owner to trim their mangroves.[xxvii] Trimming with a permit often needs to be done by a professional mangrove trimmer.[xxviii] Professional mangrove trimmers must be certified by the state.[xxix] Requiring a professional mangrove trimmer to do the more extensive trimming protects the trees from activity that is riskier for the health of the tree. Any standard trimming, whether through an exemption or done with a general permit, cannot cut a mangrove to less than 6 feet tall.[xxx] Larger trees need to be trimmed in stages, perhaps over several years, to ensure the health of the tree.[xxxi] Trimming cannot be done in such a way that damages the structure of the tree.[xxxii] Anything beyond exemption trimming and trimming through a general permit needs to be done through an individual permit.[xxxiii]

Within the confines of the existing Act, the Florida Department of Environmental Protection (FDEP) promotes different horticulture techniques in trimming mangroves in order to legally maximize homeowners' views.[xxxiv] Windowing involves selectively trimming the lower and central branches of a tree (but above 6 feet) to maintain views below the canopy.[xxxv] This still provides shade, privacy, windbreak, and habitat, especially for birds. Hedging, usually down to 6 feet, involves cutting the trees so that they look more like hedges.[xxxvi] Hedging offers a more manicured look while still maintaining density. Undercutting is the trimming of the lower portion (below 6 feet) of a mangrove tree.[xxxvii] This is not preferred, but can be allowed through an individual permit.[xxxviii] Different species of mangroves respond differently to the various trimming styles, for example, hedging is not preferred for red mangroves because red mangroves carry the majority of their tree mass at the top of the tree.[xxxix]

2.4 Coastal Population Growth and Stakeholder Assessment

NOAA defines Coastal Shoreline Counties (CSCs) in the U.S. as counties which directly border open water, major estuaries, or the Great Lakes (Crosset et al., 2013). Due to this proximity, these types of counties are the most vulnerable to coastal hazards and contain the majority of the economic value garnered by coastal activities. Moreover, while population in the general in the U.S. continues to increase overall, there are disproportionately large increases in coastal populations (Fig. 7). Between 1970 and 2012, for example, the U.S. overall grew by 36 people per square mile (/mi^2), but CSCs alone added 125 people/mi^2 (Crosset et al., 2013). Along

Figure 7. *Crossett, et al., 2013*. Population density changes in CSCs and inland counties. Population density in CSCs (blue bars) has steadily increased over the last 40 years, with a projected continued rise by the year 2020. In contrast, the overall population density and rate of increase (observed and projected) is significantly smaller for inland counties, highlighting the propensity for U.S. residents to live on the coastline.



these lines, CSCs have a higher population density than the U.S. on average, and NOAA estimates an 8% increase in CSC population between 2010 and 2020 (Crosset et al., 2013). Demographically, CSCs have comparable income and education levels of residents, but have relatively more minority racial groups than inland counties. In Florida alone, 13% of the CSC residents live in poverty (Crosset et al., 2013). This diverse population presents a unique set of social and economic vulnerabilities which could manifest clearly due to coastal property loss from erosion, declining potable water resources, and income impacts from reduced coastal ecosystem usability. In this Report, we focus on stakeholder groups whom we met and learned from directly in Cedar Key, Florida. These include coastal homeowners, recreational fishing guides, commercial fishermen, local government officials, and state environmental agencies. Coastal homeowners have economic concerns over property loss and home equity values. Recreational guides and commercial fishermen depend on water quality and juvenile habitat availability for fish stocks critical to their livelihoods. Local government officials are challenged with balancing environmental longevity with the immediate economic needs of their jurisdictions. State regulatory agencies are focused on preserving coastal resources while managing them for the enjoyment and use by Florida residents.

3. Results

Statistically significant, increasing trends in regional temperature, local sea-level, storm intensity, and seasonality all suggest that Florida's Gulf Coast is likely to experience significant changes in its local climate in the coming decades. These patterns are consistent with global trends and advanced climate models, and thus do not appear to be reversing or changing course in the foreseeable future. It is highly likely that the Big Bend will experience steadily accelerating sea-level rise, a rise in overall temperature, an increase in the frost-free season with a decrease in extremely cold days and nights, and is likely to experience an increasing number of intense hurricanes. With these increases in freeze-free periods, mangroves will continue to expand and will likely begin to dominate the landscape within the Big Bend. increasing intensity of storms means that coastal vegetation and having the best plant community in place will play an increasingly important role in coastline protection, erosion control, and sediment accretion. These climatic impacts will increase the vulnerability of this region to coastal erosion and ecosystem shifts.

In the absence of freezing temperatures, mangroves offer a number of advantages over *Spartina*. Due to more above-ground biomass they offer better storm protection. They also are able to trap significantly more carbon than *Spartina*, playing a potentially significant role in combating emissions which are accelerating climate change. Mangroves can also support many of the same fish and wildlife communities as *Spartina* as well as potentially providing important habitat to tropical species whose range is also increasing in response to increasing temperatures. However, freeze events will continue to occur and large scale mangrove die-offs may have catastrophic impacts to the environment.

In the direct path of these shifts in coastal sedimentation and wetland evolution are a steadily increasing coastal population with a diverse background and a diverse set of social and economic interests. Our interactions with the population in Cedar Key has shown that residents have vivid memories of the abandonment of Atsena Otie Key after a large hurricane, and their vulnerability is well understood. The community is engaged and interested in maximizing the longevity of Cedar Key as a coastal community with a productive economy. However, they recognize the challenges of increasing development and urbanization of the coastline as large numbers of new residents arrive each year. This demand for already limited space is intensified as encroaching sea-levels and erosion events creep up the shorelines.

Based on our scientific (2.1 and 2.2) and legal research (2.3), field observations in Cedar Key and Yankeetown, Florida (2.2), and in-person discussions with local stakeholders (2.4) , we have determined a number of results. The Big Bend is uniquely vulnerable to the impacts of climate change due to the superposition of its physical characteristics (low sediment supply) with the increasingly extreme erosive effects of sea-level rise and storm activity. Moreover, the current shift in wetland plant distributions from *Spartina* to Mangroves is potentially resulting in lower sediment accumulation rates in the short-term. However, storm events may play an increasingly important role in sediment accretion and mangroves are better at trapping sediments during these events. Additionally, as this ecosystem shifts, it generates a shoreline that is increasingly vulnerable to extreme seasonal temperature changes, with limited knowledge of the effects of a sudden freeze on a large mangrove population and the coastal sediments it anchors. Finally, the current law allows for limited management of the invading mangroves by a citizen population largely unimpressed by their ecological benefits. We propose that this combination of vulnerable coastline with varied stakeholder agendas regarding coastal wetland management requires a four-tiered management and research plan.

4. Discussion: Proposed Solutions and their Legal Framework

During our time in Cedar Key, the stakeholder concerns we suspected were confirmed. Private landowners are concerned about the legality of trimming mangroves and mangroves affecting their views. While many citizens recognize the ecological importance of mangroves, the trees still create conflict in ways that *Spartina* does not. One citizen even noted that he did not like mangroves, not because of their tendency to block views, but because they make the region look like South Florida. Because of their diminished longevity in the area caused by freezing, mangroves have never been prevalent enough to define the landscape. Thus, their recent resurgence disturbs the quintessential North Florida landscape. With these concerns in mind, several policy suggestions have been recommended.

4.1 Continuing Education and Outreach

In the past, Cedar Key has held workshops for its citizens regarding the proper trimming of mangrove trees. Our first policy recommendation is to suggest this education continue. This recommendation can be applied in conjunction with any other policy recommendation that may be instituted. Education is the key to responsible management, and citizen happiness is vital for any policy to succeed. Arming homeowners with proper trimming knowledge ensures ecological productivity, while optimizing homeowner satisfaction. Further, these workshops should be expanded, so as they explain proper trimming techniques, workshops would also educate homeowners about the environmental benefits of mangroves. Understanding mangroves' contributions to shoreline stabilization and wildlife habitat will allow homeowners to appreciate these trees for the services they offer.

4.2 Improvements to Existing Laws

There are two novels ways in which the current laws on mangroves could be improved. First, restructuring the Act to focus on more localized mangrove management. The Act is a state-wide regulation, based on the height of the mangrove tree and little else. Without resorting to the individual permit process, there is no consideration for where a mangrove tree sits geographically. Florida is a very long state, and mangroves are largely latitude-dependent. If mangroves were managed on a more local level, regional needs could be accomplished, maximizing environmental efficiency for each area. For example, Cedar Key presents a unique situation for mangroves. Because Cedar Key is on the northernmost edge of mangroves' range, freezing presents a bigger issue there than in other places in the state. Because of the ecological risks of being vulnerable to freezes, Cedar Key necessitates more localized management. Perhaps this would involve cutting down mangroves in order to maintain a diverse, and thus more resistant, ecosystem. But, no matter what sound management turns out to be, regions with localized issues could best retain flexibility in management if they had localized control.

If restructuring the Act to focus on localized control is unrealistic, individual local governments may still receive authority through the Act as it stands. The Act states that a local government may receive delegation from the state to regulate its mangroves.[xl] This section of the Act is underutilized, however. Currently, the only local governments that have been delegated the authority are Miami-Dade County, Broward County, Hillsborough County, Pinellas County, Town of Jupiter Island, City of Sanibel, and Sarasota County.[xli] Why this authorization remains underutilized is not clear. It is not a matter of the Florida Department of Environmental Protection being averse from delegating authority. The Rules on receiving delegation from FDEP for an environmental resource permit, for example, are relatively broad. A local government may receive delegation if FDEP finds that delegation would "further the goal of providing an efficient, effective and streamlined permitting system; the local government has the financial, technical, and administrative capabilities to effectively and efficiently implement and enforce the program; and protection of environmental resources will be maintained."[xlii] If those criteria were applied to mangrove regulation management, Levy County may be able to receive authority. Delegating authority to Levy County would result in a more efficient permitting system because the geography of Levy County presents special circumstances that will require more general and individual permits in the future. Internalizing the permitting process would avoid the bureaucratic delays of going to the state for every permit under the Act. The protection of environmental resources will be maintained because regulating itself will allow for the time, attention, and local knowledge necessary to make the best environmental decision for each application. As long as it possesses sufficient financial, technical and administrative capabilities, Levy County could affectively argue that it should receive local government delegation to regulate mangroves.

If Levy County were to receive authority, it would be in charge of distributing permits for mangrove trimming. Equipped with local knowledge of its individual needs, Levy County could efficiently govern the distribution of permits within its jurisdiction. The ability of homeowners to trim their mangroves within the exemptions of the Act cannot be restricted by a delegated local government.[xliii] The local government can, however, impose stricter substantive standards or procedural requirements for people seeking individual permits.[xliv] Individual permits allow for trimming that goes beyond the 6 foot general permit requirement; it even allows for the removal of mangroves if the proposed activity meets the individual permit criteria (discussed infra).[xlv] The County could offset more generous trimming allowances with stricter procedural requirements to obtain a permit, for example. With this flexibility, Levy County could address its localized needs. This delegation of authority would also be helpful in achieving specialized service management, discussed below.

The second novel way in which mangrove policy could be improved is to allow for the management of mangroves based on individual ecosystem services. In general, the Act works to preserve mangroves so that their habitat enjoys all the ecosystem services that mangroves provide. But in areas where mangroves are met with more contention, it should be possible to manipulate them in a way to achieve only those services that are most needed. Instead of blanket rules based on height, mangroves could be managed based on what benefit is necessary for that location.

In some places, such as uninhabited islands off the coast, mangroves may be most beneficial being left untouched. Mangroves stabilize the sediment to keep the land intact, break up big winds and rains coming from offshore, provide habitat for myriad species, sequester as much carbon as possible, and do not interfere with anyone's views. In this case, the mangroves would be managed to enjoy all their ecosystem services. In others situations, mangroves may only be needed for one or two ecosystem services. Mangroves located inland might only be necessary for habitat productivity and carbon sequestration. In that case, they could be trimmed in a way that maintains a large canopy for birds but becomes thinner towards the base. In some places, such as on a heavily receding shoreline, mangroves may be needed primarily for sediment stabilization. Here, the mangroves' roots are most important, and more liberal trimming of the leaves would be permitted. In other locations, storm surge protection is the primary concern, so the best management practice would be to promote bulky foliage columns. Specialized service management can address an infinite number of potential circumstances because of its focus on the case at hand. Picking and choosing the ecosystem service provided by a mangrove allows people to appreciate the mangrove tree for supplying what they need, while not burdening them with what they do not need.

A very basic form of specialized service management is exhibited by the existing horticulture techniques promoted by the FDEP. Windowing, for example, provides habitat for birds and stabilizes sediment, but sacrifices storm surge protection for a view. Hence, specialized service management could be achieved without changing the law. Specialized service management goes beyond general permits (and thus beyond current horticulture techniques), but applicants could achieve the results they desire through individual permits.[xlvi] Widespread utilization of this policy would mean an avalanche of individual permit applications to the FDEP, thus, specialized service management would work best when used in conjunction with localized control.

4.3 Short-Term Shoreline Restoration

Shoreline revegetation/restoration projects within the Big Bend region must decide what type of plant community (mangroves or *Spartina*) will best accomplish the goals of the project. Over the short-term *Spartina* generally wins out and yields the best results for a number of reasons. *Spartina* is less expensive and quicker to plant. As many projects are limited in scale logistically and financially, being a lower cost option helps make *Spartina* more practical. In addition, due to its faster growth and establishment rates *Spartina* will begin stabilizing sediments and providing ecosystem services sooner than mangroves. Many shoreline restoration projects occur near populated areas and planting a vegetation type that stays short and does not impede people's view is often an important factor in receiving public support. Therefore *Spartina* being a grass makes it more favorable in this area as well. Finally and perhaps most important, is the fact that *Spartina* is freeze tolerant and mangroves are not. So, over the short term, mangroves are a risky choice because we cannot predict when the next freeze event will occur, and if one does occur and kills of all the newly planted mangroves, the restoration project may rapidly return to its degraded, pre-restored condition.

4.4 Long-Term Policy: Research

Within the Big Bend, mangroves are rapidly becoming more abundant. While this establishment of mangroves does offer a number of benefits to the region (carbon sequestration, storm protection, increased habitat diversity, etc.), there is an underlying concern of what will happen when freeze events do occur. Historically, small numbers of mangroves dying during freezes had trivial impacts on the environment. As mangroves become the dominant marsh plant these die-offs have potentially catastrophic impacts. Unfortunately these types of mass die offs are relatively unstudied, especially within the Big Bend.

When mangroves freeze, they rapidly drop all their leaves, which have high levels of carbon and nitrogen (Ellis et al. 2006). As these leaves decompose, they release nutrients. This sudden pulse of nutrients into the water can cause negative water quality issues including algal blooms, and increased turbidity. These sudden water quality issues may have large impacts on the fisheries dependent on these areas. The extent and duration of these water quality impacts are currently unknown for the region. Sudden defoliation of mangroves also directly impacts fish and wildlife communities that directly use the mangroves for cover or foraging opportunities. These events essentially change the habitat and how animals utilize the area. Finally, while dead mangroves have been shown to continue to hold sediments, it is unlikely this service will continue if a die off is followed by a large storm event.

Historically, when the small numbers of mangroves in the Big Bend died due to freeze events, *Spartina* salt marsh rapidly re-established these areas. However, if these die-offs cover a much larger area, it is unclear how long it would take the area to be revegetated. In addition, it is currently unknown what type of ecosystem impacts may be related to cycling back and forth between *Spartina* salt marsh and mangrove forests.

More research is needed before a long-term policy suggestion can be made. Specifically, testing the actual impacts of a large mangrove die-off. This may include purposely killing an area of mangroves to study how the ecosystem responds and its ability to recover. To gather that research, mangroves will need to be manipulated in ways that would violate the law. Specifically, to test how an ecosystem would respond to a mass mangrove die-off, researchers would have to kill off masses of mangroves. Amending the law would be an option, but without amending the law, this can still be accomplished in three potential ways: an individual permit, government exemption, or a variance.

Researchers could apply for an individual permit to accomplish their research goals.[xlvii] Individual permits are subject to review under FS § 373.414(1) and (8).[xlviii] These sections require the applicant to demonstrate that the proposed activity will not be harmful to water resources, will not be inconsistent with the overall purpose of the statutes, and will not be contrary to the public interest.[xlix] The research would have to be done under controlled conditions such that it would not be harmful to water resources. Studies on the benefits of mangroves would be consistent with the purpose of the Act because it would further the legislative finding that mangroves are beneficial to the ecosystem.[l] One purpose of the Act is to encourage mangrove growth and planting, so research on how mangroves can help an area would certainly promote this purpose.[li]

In determining whether the activity is within the public interest, the state considers whether the activity adversely affects public health, safety, welfare, or property of others, the conservation of fish and wildlife, the navigation, flow of water or erosion, the fishing and marine productivity of the area, whether the activity will be temporary or permanent, and the value of the functions being performed by the areas affected by the proposed activity.[lii] Mangrove research would not adversely affect public health, safety, or welfare of others; if anything, it would enhance the public health, safety, and welfare in the long run. The research we've proposed would probably affect the property of others, however. It also may affect the conservation of fish and wildlife, flow of water, erosion, and marine productivity in the short term, but it would supplement future policies that promote these things in the long run. The activity would be temporary, but it would adversely affect functions being performed in the area. An activity does not have to meet all the criteria to be within the public interest.[liii] Instead, the governing department performs a balancing test based on the criteria.[liv] An applicant's proposed mitigation can also be considered when reviewing a permit application.[lv] Weighed together, researchers may be able to argue that their research is within the public interest, and thus receive an individual permit.

If researchers cannot obtain an individual permit, their goals may still be achieved through a government exemption, if the research is done by or contracted out by the government. The Act contains an exemption for "[t]he trimming of mangrove trees by…a federal, state, county, or municipal agency…when the trimming is done as a governmental function of the agency."[lvi] Government-sponsored research could fall within this exception if it was being done as a governmental function of an agency. Even private research with government clearance could potentially fall within this exception. The FDEP is the best candidate for receiving this exemption because mangroves are already within its jurisdiction. The trimming would just have to be done "as a governmental function of the agency."[lvii] Though there is no enumerated function of the FDEP regarding research of ecosystem resiliency, there are several explicit agency responsibilities that this type of research may fall under: "Identifying new management strategies to achieve the goal of maximizing the protection and conservation of ocean and coastal resources…", "[m]anaging and enhancing Florida's submerged lands and coastal uplands", "[a]ssessing and improving the quality and ecological health of Florida's waters and aquatic ecosystems…", and "[p]roviding reliable and valid laboratory analyses…".[lviii] Unfortunately, there is no existing case law that defines what the Act means by "governmental function". The only case that even addresses the question of what "governmental function" means is *State Dept. of Environmental Regulation v. Monroe County*.[lix] In that case, the court held that cutting mangroves near an airport to comply with Federal Aviation Administration regulations would be a governmental function, and remanded to decide if that was what Monroe County was doing.[lx] But, even without case law to support the interpretation, the FDEP or a smaller municipality may be able to cut down mangroves in accordance with a government exemption, as long as the activity is done in furtherance of performing a governmental function.

If researchers cannot obtain an individual permit or a government exemption, they still may be able to receive a variance.[lxi] A variance allows for certain noncompliance with a law if compliance would result in a unique and unnecessary hardship, and the hardship is not self-imposed.[lxii] The hardship must be unique to the situation and not a general condition of many others.[lxiii] A variance also must be consistent with the general purpose of the Act.[lxiv] The FDEP has wide discretion in granting variances.[lxv] Demonstrated research needs may be able to qualify as a unique and unnecessary hardship. Climate change is causing mangroves to spread northward, presenting a unique problem in Cedar Key. Freezing and the long-term resiliency of mangroves presents a bigger issue in Cedar Key than elsewhere in the state. Thus, this gap in research may qualify as a unique hardship. Further, the hardship is unnecessary because the Act is restricting legitimate scientific efforts to understand the impacts of a changing landscape. The hardship is not self-imposed, as the change in mangrove distribution is natural, and the researchers who would apply for this variance did not contribute to the changes, nor the regulations imposed by the Act. The kind of research proposed is consistent with the purpose of the Act because it will be used to implement policy that protects and preserves mangrove resources, and hopefully, encourages the planting and maintaining of mangroves by private homeowners.[lxvi]

With a variety of legal avenues, further research into long-term mangrove effects should be able to be achieved. Until that point, specific policy for a 40-year time scale is risky and would be irresponsible to suggest.

5. Conclusions and Strategic Recommendations

- Accelerating sea-level rise and erosion events are in direct contention with the growing demand for coastal property by larger numbers of people moving to coastal areas each year.
- The coastal wetland vegetation ecotone plays a critical role in stabilizing and maintaining usable shoreline property.
- Due to warming temperatures, mangroves will continue to become more abundant in the Big Bend region. However, freeze events will still occur and may result in large die-off of mangroves.
- Mangroves offer multiple ecosystem services that benefit coastal communities including storm protection, and wildlife habitat.
    - ***We recommend continuing education and training for Big Bend area residents on proper mangrove trimming techniques and the benefits of mangroves for their property.***
- Mangroves are protected by state law, whereas, beyond light trimming, landowners cannot trim or cut them down without a permit from the state.
    - ***We recommend some modifications to the existing law protecting mangroves, in order to harmonize homeowner happiness with environmental productivity:***
        - ***Allow more localized control of mangrove protection and permitting, rather than relying on the state.***
        - ***Allow for the specialized service management of mangroves.***
- Short-term restoration will benefit from using *Spartina* because of its lower cost, rapid growth, freeze tolerance and it does not impede people's view.
    - ***We recommend promoting Spartina growth for short-term ecosystem management.***

- Over the long term it is unknown how large mangrove die-off events due to freezes may impact the ecosystem. These impacts may include nutrient pulses, habitat loss, erosion and cycling between habitat types.
    - ***We recommend further research into the effects of mangroves on this region, specifically research into the effects of mass mangrove die-offs, in order to effectively plan mangrove-Spartina management in the long-term.***
    - ***To accomplish this legally, we recommend researchers:***
        - ***Apply for an individual permit.***
        - ***Seek a government exemption.***
        - ***Apply for a variance.***

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[i] FS § 403.9321–33.
[ii] FS § 403.9328.
[iii] FS § 403.9322.
[iv] Id.
[v] FS § 403.9323.
[vi] Id.
[vii] Mangrove Trimming Guidelines for Homeowners, Florida Department of Environmental Protection, 8.
[viii] Tyler v. Wilkinson, 24 F. Cas. 472, No. 14312 (C.C.D. R.I. 1827).
[ix] L. of Water Rights and Resources § 3:7 (2016).
[x] St. Clair County v. Lovingston, 90 U.S. 46, 68–69 (1874).
[xi] Id.
[xii] Id.
[xiii] L. of Water Rights and Resources § 3:42 (2016).
[xiv] Id.
[xv] See Part 2.1, supra.
[xvi] 56 Fla. Jur 2d Water § 183.
[xvii] Id.
[xviii] Art. X, § 11, Fla. Const.
[xix] 56 Fla. Jur 2d Water § 148.
[xx] See Part 2.2, supra.
[xxi] FS § 403.9321–33.
[xxii] FS § 403.9323(1).
[xxiii] FS § 403.9322(2).
[xxiv] FS § 403.9323(3).
[xxv] FS § 403.9326(1)(a).
[xxvi] FS § 403.9326(1)(d).
[xxvii] FS § 403.9327.
[xxviii] Id.
[xxix] FS § 403.9329.
[xxx] FS § 403.9327.
[xxxi] FS § 403.9328.
[xxxii] Id.
[xxxiii] Id.
[xxxiv] Mangrove Trimming Guidelines for Homeowners, Florida Department of Environmental Protection, 8.
[xxxv] Id.
[xxxvi] Id.

[xxxvii] Id.
[xxxviii] Id.
[xxxix] Id.
[xl] FS § 403.9324(6).
[xli] Delegated Local Governments, Florida Department of Environmental Protection, http://www.dep.state.fl.us/water/wetlands/mangroves/mangrove_trimming.htm.
[xlii] Fla. Admin. Code. R. 62-344.500(1).
[xliii] FS 403.9324(6).
[xliv] Id.
[xlv] FS § 403.9328(2)(a).
[xlvi] Id.
[xlvii] Id.
[xlviii] Id.
[xlix] FS § 373.414(1).
[l] FS § 403.9322.
[li] FS § 403.9323.
[lii] FS § 373.414(1)(a).
[liii] Id.
[liv] Id.
[lv] FS § 403.9328(2)(a).
[lvi] FS § 403.9326(1)(f).
[lvii] Id.
[lviii] Agency Purposes & Authority, Florida Department of Environmental Protection, http://www.dep.state.fl.us/mainpage/about/statement.pdf.
[lix] 610 So.2d 697 (1993).
[lx] Id. at 698–99.
[lxi] FS § 403.9333.
[lxii] W. Thomas Hawkins, Land Use Law Course Supplement 101 (2016).
[lxiii] Id. at 101.
[lxiv] FS § 403.9333.
[lxv] Id.
[lxvi] FS § 403.9323(1), (4).