REGIONAL SEA LEVEL RISE, CLIMATE CHANGE, AND SPECIES ADAPTATION SCENARIOS FOR FLORIDA

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Sustainability Leadership Service Learning Project Old Dominion University

Undergraduates

Peter Ahl
Park Recreation and Tourism Studies
Brooke Bass
Biology
Brittany Germain
Biology
Gabriela Giacomangeli
Biology
Caroline Haymaker
Biology
Nikolai Karlov
Biology
Karlie Pritchard
Biology
Teri Ramey
Biology
Kahlil Scribner, Editor-In-Chief
Marine Biology
Elaina Simpson
Biology

Professors

Dr. Tatyana Lobova
Ph.D in Botany, Komarov Botanical Institute, Russian Academy of Sciences (2000), M.S. in Biology/Botany, St. Petersburg State University (1994), Senior Lecturer of Department of Biological Sciences.
Michelle Heart
M.A. in English, Professional Writing, Old Dominion University (2007), B.A. in English, Professional Writing, Old Dominion University (2005), Lecturer of English.
Dr. Hans-Peter Plag
Ph.D. in Natural Science, Free University of Berlin (1988), Professor of Ocean, Earth, & Atmospheric Sciences

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Executive Summary

This report serves the purpose of delineating the hazards and vulnerabilities affecting the ecosystems, habitats, and non-human animal populations of the southeastern coast of Florida that are induced by climate change, sea-level rise, and anthropogenic land changes. The recommendations and options we present will serve the purpose of becoming the basis for adaptation strategies that can be applied to the system(s) we discuss. We will use and compartmentalize system knowledge in order to understand the answers to the questions (Figure 1):

- What might happen to the system?
- What are the possible threats and hazards?
- What do we want to happen? (Goal Knowledge)
- How can we impact the system trajectory (Transformation Knowledge)

Hazards Posed to Coastal Ecosystems

Florida faces a cavalcade of hazards currently from climate change, sea-level rise, and human induced impacts. From climate change the Floridian coast experiences temperature increase, heat waves, snap freezes, intensified tropical storms, increased precipitation, severe droughts, wildfires, and ocean acidification. Sea-level rise threatens coastal ecosystems with inundation which also introduces the problem of salinification, erosion, accretion of sediment, and migration of said coastal ecosystems. Human induced hazards also exist which can manifest themselves as developed coastlines that prevent migration of coastal ecosystems landward to escape sea-level rise.

Vulnerabilities of Coastal Ecosystems

The various ecosystems present on Florida's coast are vulnerable to the hazards listed above primarily because of their geometry. Coastal ecosystems have the disadvantage of being located in close proximity to the water as is the case with Pelican Island within the Indian River Lagoon which puts them directly in the path of sea-level rise. Many plant and non-human animal species are very vulnerable to sea-level rise as they rely on specific habitat types that can only tolerate a very limited range of salinity and sea-level such as mangroves and seagrasses. These species are also vulnerable to climate-change induced hazards such as droughts, snap freezes, and increased precipitation. Beach communities are supremely vulnerable to erosion especially on coastal areas where anthropogenic development exists and impedes the beach's ability to slowly migrate inland with sea-level rise. Species like the beach mouse or the sea turtle possess limited options in this case as they must either find new beaches to settle or die out. The process of procreation is also vulnerable to several climate change induced hazards as is the case with sea turtles: the increased ambient temperature causing more females to be born rather than males resulting in a disparity in the gender dichotomy. The extreme result of rising temperatures on the beaches where sea turtles lay their eggs is that the eggs will become boiled and never yield viable offspring. This could result in the decline and possible extinction of certain species.

Recommendations for Improving Decision Making

In order to safeguard the integrity of the coastal ecosystems on Florida's eastern coast it is entirely necessary that transformation knowledge be developed and implemented into the system (Figure 2). Transformation knowledge is the knowledge possessed in order to impact the system trajectory. Adaptation strategies must be designed to be dynamic and change with the system. To ensure this we recommend continuously monitoring habitats to identify potential developing hazards posed to the system(s) and adapting the strategies to accommodate developing hazards. We recommend monitoring at regular intervals and reassessments occur at least once every four to five years. To the end of increasing habitat resilience to climate change induced hazards and sea-level rise we recommend that key locations be fortified tailored to their needs to increase resilience to ecosystem hazards. In order to mitigate the effects of wildfires we recommend implementing prescribed burns. We also recommend identification of new potential locations where Pelican Island-like islands might emerge because fortification against sea-level rise is not a feasible permanent solution. Pelican Island National Wildlife Refuge is facing grim projections of sea-level rise and to combat this we recommend that sediment accretion be used in tandem with wave attenuation to mitigate the effect wave energy will have on coastal ecosystems. Permeable structures such as rip rap cribs and bags of oysters are possible methods of attenuating the water of the lagoon around the islands. For several coastal ecosystems such as the beaches it is also necessary to ensure that they are allowed to migrate naturally. To do this we stress the importance of securing and maintaining corridors and pathways for these ecosystems to travel and limiting the amount of development allowed on the coast.

For vulnerable species such as the sea turtle we recommend continued monitoring of the species and evaluation of the beaches it uses for egg laying. We urge protection of beaches sea turtles commonly utilize to lay and bury their eggs and those beaches with minimal anthropogenic development must be prioritized over ones in decline. Species like the beach mouse have experienced declines in their local populations as of June 2017 and we recommend prioritizing areas and beaches that show promise for sustaining them into the future. In order to increase populations of vulnerable species populations we recommend implementing constant monitoring of local species and translocating small groups to areas which possess more favorable qualities and less anthropogenic development.

We emphasize the importance of educating the public by increasing their intimacy with the surrounding non-human environment and species. Bring them out to Pelican Island National Wildlife Refuge. Show them the damage sea-level rise and climate change can have on their precious coastal ecosystems. Frequent reassessment must also occur to make sure that these systems are responding to climate change and sea-level rise as projected. In order to make sure the participating organizations/agencies stay up to date on the nature of the hazards and vulnerabilities threatening Florida's coastal ecosystem we recommend:

- Training/Developing a comprehensive knowledge of the system(s) by performing studies and research

- Partnering with local colleges and institutions to perform research on these coastal ecosystems to assess the success of implemented adaptation strategies.

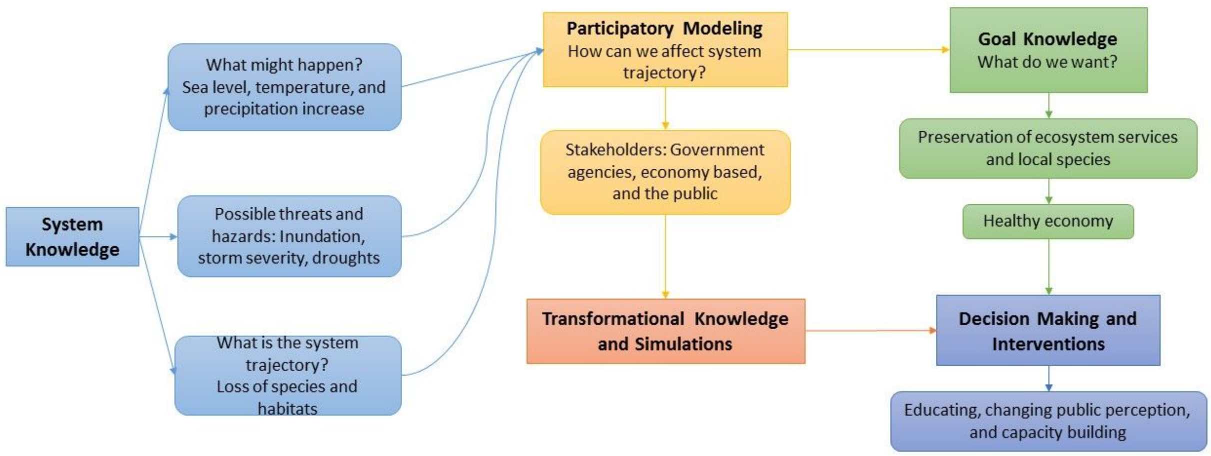

Figure 1: Society-based Sustainability Flowchart. With a comprehensive understanding of the system knowledge and stakeholders, participatory modeling can be developed. Goal transformational knowledge can then be extrapolated from participatory modeling so that viable decision making and interventions can be established and implemented.

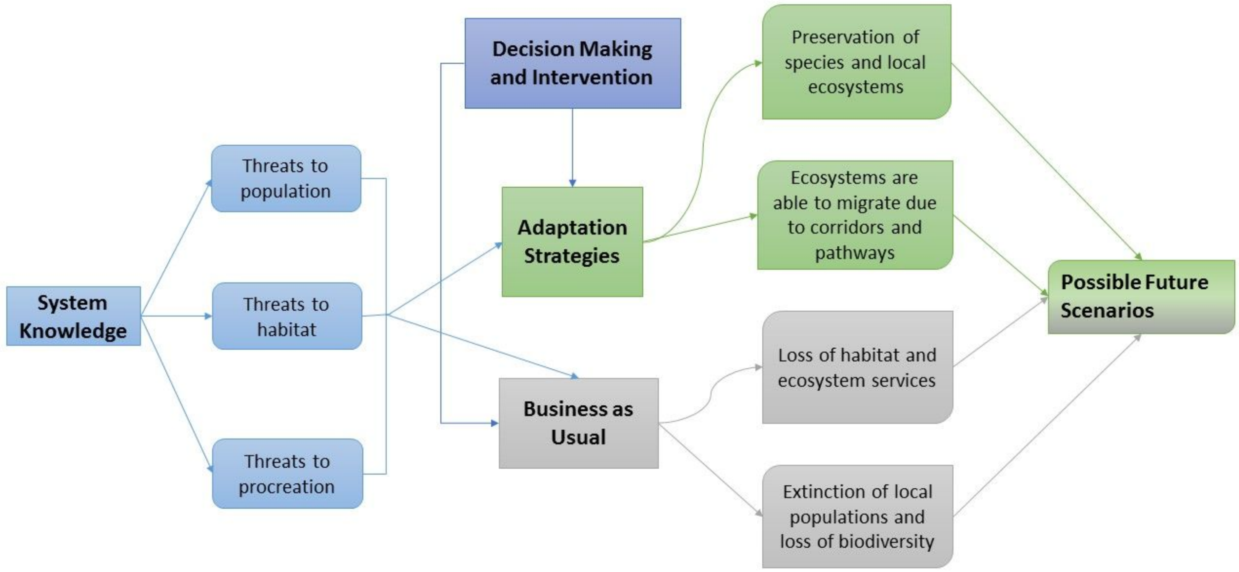

Figure 2: Adaptation-based Sustainability Flowchart. A combination of decision making and system knowledge can lead to advantageous adaptation strategies or strategies that do not aid in creating a sustainable system for future scenarios.

1 INTRODUCTION

1.1 SEA LEVEL RISE AND COASTAL ECOSYSTEMS

Pelican Island National Wildlife Refuge (NWR), for short, located just off the coastline of eastern Florida in the Indian River Lagoon, is our nation's first established national wildlife refuge. It is part of the barrier island and lagoon system that extends along the coast. There are ten different habitat types that make up the refuge, and they are divided into three ecological community categories: aquatic, transitional, and uplands.

Important constituents of the aquatic community are oyster beds, seagrasses, and open estuarine waters. Mangrove swamps are a key component for transitional communities. Found along the shoreline of the lagoon, they aid in stabilizing the land and sediment. Upland habitats include islands, hammocks, and citrus groves. Ecosystems we have focused on are freshwater-forested wetlands, freshwater emergent wetlands, brackish marshes, saltwater marshes, mangroves, and coastal dunes. The Indian River Lagoon system is fed by several freshwater rivers, creeks, and canals, and the transition from freshwater to saltwater provides a basis for the diversity of wildlife in this area (U.S. Fish & Wildlife Service, 2006). Therefore, the protection and restoration of these habitats in and around Pelican Island NWR are important.

The climate of the refuge is subtropical and temperate, and therefore is susceptible to tropical storms. From east to west, the elevation of the refuge rises from sea level to 4.6m, then declines below sea level in the Indian River Lagoon (U.S. Fish & Wildlife Service, 2006). Due to its proximity to the Atlantic Ocean the refuge is faced with seawater intrusion (SWI) in the form of flooding and inundation. The chance of these events occurring increases during strong or detrimental weather conditions.

Barrier islands make up about an eighth of global coastlines. They protect mainland coastal areas from storm surges and wave energy originating in the open ocean. The barrier island system in which Pelican Island is located shields the refuge from the effects of these events that threaten the biodiversity and ecological communities. This system also protects the surrounding Florida mainland and its rapidly increasing population. These barrier islands are therefore important in conserving the biodiversity found along Florida's east coast. Rising sea levels are expected to cause more intense storms, resulting in plant-species composition changes of the barrier islands (Zinnert et al., 2017).

Among others, this report discusses and analyzes the hazards and vulnerabilities the ecosystems of Pelican Island NWR and the barrier island system may face under various plausible sea level rise (SLR) scenarios. Analysis of the threats and foresights have aided the development of options and recommendations to facilitate the adaptation of these systems to sea level rise.

1.2 CLIMATE CHANGE AND ECOSYSTEMS

Human activities have greatly contributed to numerous factors that are driving climate change. Over the last century, the burning of fossil fuels such as coal and oil, for automobiles, factories, and electricity production, has increased the concentration of carbon dioxide in the atmosphere. Elevated levels of carbon dioxide and other Greenhouse Gases (GHGs) in the atmosphere are the biggest “drivers” of climate change caused by humans. In addition to burning of fossil fuels, clearing of land for agriculture, development and other industry needs contributes to the greenhouse effect. Other contributors include methane released from landfills and agriculture, especially from the grazing animals, and nitrous oxide from fertilizers. Increasing the GHGs in the atmosphere will lead to, on average, Earth becoming warmer. This will affect the current precipitation trends we have been seeing. With an increase in heat, the glaciers and ice will melt faster leading to an increase in sea level and the oceans will warm causing them to expand and also influence sea level rise. The world’s population is around 7.5 billion and expected to grow to be around eleven billion by 2100.

At present, Florida is home to over eighteen million people and the population is expected to increase to over 25 million by 2030 and even to 35 million by 2060 (Irizarry-Ortiz et al., 2013). An increase in population means there will be an increase in development, an increase in food production and an increase in transportation needs. Climate change is already affecting different ecosystems in Florida, like the ones on Pelican and Merritt Island, and the increase in population will only accelerate these changes.

Pelican Island was the first federal area to be set aside in 1903 to specifically protect wildlife and was dedicated as a National Historic Landmark in 1963. Over 140 species of birds use the Refuge for nesting, feeding and roofing. Over 200 species of fish are on the refuge including pipefish, goby, black mullet, ladyfish and American eel. Pelican Island is home to 14 federally listed threatened and endangered species and 45 species listed by the State of Florida. The lagoon is used commonly by Atlantic bottlenose dolphins and West Indian manatees. Pelican Island has numerous different types of habitats including lagoonal waters, lakes, mangrove swamps, and hardwood forest (U. S. Fish and Wildlife Service, 2002).

Sea grasses are submerged vascular plants that form dense communities in shallow waters and can grow in highly variable salinity environments. Coastal lagoons and estuaries in south Florida depend on seagrasses as they are an ecologically important habitat. Seagrasses provide food for high trophic organisms and the density of these grasses provide shelter and protection to some species. Many federally listed animals such as the American crocodile, loggerhead turtle, leatherback sea turtle, wood stork, and West Indian manatee, depend on or utilize seagrass in one form or another (Jennings, 1999).

Mangroves are a vital component of Pelican Island. They provide a habitat for some reptiles and mammals, cover and foraging grounds for birds, and provide protected nursery areas for fish, crustaceans, and shellfish. Mangroves recycle nutrients and keep a balance of nutrients in the estuarine ecosystem. Mangroves can be a source of food for some species through their leaves, roots, wood, and detrital materials. There are more than 554,000 acres of mangroves in central and South Florida. This vital ecosystem serves as storm buffers by providing windbreaks and through prop root baffling of wave action. The roots of mangroves stabilize shorelines and fine substrates, which leads to increased water clarity and less turbidity (Jennings, 1999).

Coastal economies and ecosystems have historically depended on oyster reefs. As generations of oysters pile on top of each other, they grow and form reefs that can also provide habitats for many species. Oysters are ancient and important benthic components of these ecosystems. Oyster reefs filter particulates, nutrients, sediments and phytoplankton which allows light to penetrate deeper into the water allowing for increased growth of submerged aquatic vegetation. Oysters also reduce the amount of nitrogen in the water column and minimize the effects of eutrophication. These reefs help protect the shoreline and other ecosystems such as mangroves and marshes, by mitigating waves and reducing erosion. Additionally, they remove carbon dioxide from the water by forming calcium carbonate shells, which reduces the concentration of greenhouse gases.

Merritt Island National Refuge is located along Florida's east central coast about 60 miles east of Orland in Brevard and Volusia counties and was established in 1963 to provide a buffer zone for the National Aeronautics and Space Administration (NASA). John F. Kennedy Space Center is located on Merritt island. Almost half the refuge's 140,000 acres consist of brackish estuaries and marshes and the remaining part is a variety of coastal dunes, scrub oaks, pine forests and flatwoods and palm and oak hammocks. The refuge is vital space for important bird rookeries, a juvenile sea turtle nursery, sea turtle nesting beaches, fish spawning and settlement sites, and important manatee habitat (U.S. Fish & Wildlife Service, 2006).

Florida scrub occurs in well-drained areas that are usually deep and have sandy soils. Scrub has a patchy distribution and can be found inland and coastal areas. Scrub is dominated here by xeromorphic shrubs, mainly oak. Ground cover is usually absent. This habitat is an endangered and rapidly disappearing in Florida. A lot of species here require fire to survive or reproduce. Scrub is a fire-dependent community that relies on occasional fire, every 10-20 years, to help increase its stature, structure and appearance until the next fire (Jennings, 1999)

Pine flatwoods are unique to South Florida and provide a valuable forested habitat for wildlife and has the highest plant species diversity of any habitat in South Florida. This habitat can function seasonally as both a wetland and an upland and has a dynamic equilibrium between fire and water. Only 9% of pine flatwoods are protected and face danger from urban development as well as climate change (Jennings, 1999). They usually occur on relatively flat, poorly drained terrain. Most all plants and animals living in this ecosystem are adapted to periodic fires and the variation in structure of this community can be associated with fire. Without regular fire, pine flatwoods would transform into hardwoods dominated forests with a closed canopy, eliminating many of the plant species that currently reside there (Jennings, 1999).

1.3 SPECIES

The state of Florida has over 1,350 miles of generalized coastline, more than any other state in the continental United States (FDEP, 2014). Along those shores, there is a broad range of ecosystems and habitats that are vital to the survival of an extensive list of species including many that hold a spot on the IUCN Red List for Threatened Species. While extinction has been in the past a natural process that has been seen to occur regularly throughout history, the rate of extinction has dramatically increased with a rising human population and the onset of rapid technological advancements. Biodiversity loss is one of the most evident and well-documented cases of global change related to anthropogenic activity. In an effort to combat and mitigate this loss and preserve the roles these species play in the ecosystem, the United States created the Endangered Species Act (ESA) in 1973. The US Fish and Wildlife Service is now the sole administrator of the ESA and has the responsibility to create comprehensive adaptation plans to aid in the recovery of threatened and endangered species many of which live within the boundaries of several National Wildlife Refuges. However, there are still several species that do not have a comprehensive adaptation plan developed. Our team identified the Loggerhead Sea Turtle (*Caretta caretta*) and the Southeastern Beach Mouse (*Peromyscus polionotus niveiventris*) as two species in critical need of adaptation planning. However, we would like to use a holistic approach to adaptation planning, rather than the traditional approach specific to each species, which would consider the ecosystem as whole to be important in the conservation and adaptation of any threatened or endangered species. In this manner, we believe adaptation planning will be able to achieve greater effectiveness and efficiency while gaining many added benefits that could cultivate the interest of additional stakeholders in the process.

The Loggerhead Sea Turtle is one of several species of sea turtles protected under the ESA. Many of these turtles also nest alongside the Loggerhead down the length of Florida's coast. However, none have as large of a presence as the Loggerhead in the Archie Carr Refuge. Rivaling Oman, this section of Florida is considerably the most important nesting site for these turtles in the world.

The Southeastern Beach Mouse is a species that has a listing status of threatened. Although there are many subspecies, the Southeastern Beach Mouse is the largest of its kind and is most commonly found on the beaches of Florida and Alabama. The habitat for the beach mice usually consists of burrows in dunes which are sometimes borrowed from ghost crabs. The beach mice burrow and then use the root systems of the dune grasses to help support their tunnels. Dune grasses such as palmetto, sea grapes, and wax myrtles that help keep their burrows stable are also what they feed on. If sea oats within the dune grasses are destroyed, the mice are then resorted to eating invertebrate insects or moving on to another location. Beach mice are also nocturnal and scavenge for food at night. This leads to a high predation risk. Because so many mice are hunted by other animals, their litters yield a high mortality. The mice have about one to four pups per litter and become sexually mature at six weeks old. Even though this is a young age to become sexually mature, the average lifespan of these mice are only six months to a year. This extremely short-lived mammal is important to their habitat because they are seen as an indicator species. This means that a healthy population of beach mice leads to healthy dunes which in turn provide reinforced protection for other habitats within close proximity; including anthropogenic coastline developments.

2 HAZARDS

2.1 SEA-LEVEL RISE RELATED HAZARDS

Rising sea levels expose coastal ecosystems to inundation, erosion, overwash, and the accretion and migration of plant communities (Larson, 2010). These hazards pose extreme risks to the foundation of the barrier island system and the coastline of southeastern Florida, potentially disrupting the dynamics of the intricate interactions, and altering the landscape and ecosystems that thrive here. Taken individually, these threats alone have a major impact, but incorporated together with other natural and anthropogenic hazards, the results can be catastrophic.

Inundation of the barrier islands and coastline puts stress on the plants that make up the landscape. Mangroves, freshwater, brackish/transitional and saltwater marsh plants, and dune grasses will be affected the most (Pelican Island National Wildlife Refuge, 2016). Increased flooding and salinization will inhibit the area and space allotted for these plants to grow, acquisition of needed nutrients, and ultimately their reproduction and reproductive success. While freshwater plants and dune grasses will face the most severe hardships, other species, such as the mangroves and the flora that dominate the brackish/transitional and saltwater marshes of the islands, will fare only slightly better with the incursion of saltwater (Larson, 2010).

Erosion, on the other hand, presents another set of dangers, not just to the native vegetation, but also to the physical geography of the island itself. Increasing wave action, whether natural, such as storm surges, or anthropogenic, such as boat wake, will decrease sediment accumulation and increase washing away of current sediments (Morton, 2003). Mangroves have the potential to counteract this loss using their prop roots to trap sediments in the water, building up and stabilizing the coastline. Dunes also aid in counteracting erosion by barring the coast from increasing wave action.

Overwash, while being similar to inundation, differs in its temporariness, and is referenced in the realm of flooding from storms, such as hurricanes that make landfall. While the effects of overwash may be felt in the long-term, most of the damage is done in the short-term. The short-term effects include the destruction of dunes and decline of the grasses that hold them together, and essentially the “drowning” of various plant species. While most of the vegetation on the barrier islands is adapted to various influxes of water, the rapid rate of flooding combined with increased salinification of the waters will have a deadly effect.

Accretion and migration of plant communities can be thought of as both a hazard and an adaptation (Florida Oceans and Coastal Council, 2010). Its relevancy as a hazard stems from the changing landscape of the barrier islands. As land is rapidly lost to sea level rise, and saltwater permeates all surrounding waters, the ecosystems will begin shifting. Positive effects of this shift will be felt for those species best able to adapt and move, but negative repercussions will be felt for other species that will either not be able to adapt as quickly, or are outcompeted by those better suited to the rapidly changing landscape. Those species most at risk for destruction include the dune grasses and freshwater marsh and forested wetland plants, due to their high vulnerability to changes in the amount of, and salt content of the encroaching waters. Brackish/transitional wetland plants will also struggle to maintain a foothold (literally) in the soil, as saltwater marsh plants and mangroves migrate into their habitat.

The hazards of sea level rise are not static, and are not isolated in their effects on the landscape, habitats, and ecosystems that call Pelican Island and the surrounding barrier islands home. These threats are dynamic, working together and in opposition, both as causal and influential factors on the flora, fauna, and physical topography of the islands. Without human involvement, both directly and indirectly, these ecosystems would adapt differently, with the selective preference for those species that can exist in the new conditions being a main driver. The problems and issues surrounding the islands' ability to adapt and change are, more often than not, hindered by anthropogenic causes. Erosion and the plant communities' ability to accrete and migrate are exacerbated and hindered by development, tourism and recreational activities, and human needs for land, water, food, and other natural resources.

2.2 CLIMATE CHANGE RELATED HAZARDS

Florida's climate is strongly affected by the Gulf of Mexico and the Atlantic Ocean and is greatly influenced by a variety of local, global, natural and anthropogenic factors. Models that incorporate the effects of the Atlantic Multidecadal Oscillation, the El Niño Southern Oscillation, and the North Atlantic Oscillation are necessary for more reliable projections (Irizarry-Ortiz et al., 2013). Since 1991, average temperatures in south Florida have increased by 1.5ºC and 1ºC to 1.5ºC in central Florida. Average annual temperatures in Florida are projected to increase by +3 to 7°C by the end of the 21st century (NCA, 2014). Along with increased temperature, heat waves are also projected to increase. The State of Florida will see an increase in days over 35°C, specifically western and southwestern Florida will have at least an additional 50 days, interior of Florida will have at least an additional 40-50 days, and the coastal areas will see an increase between 30-40 days which is shown in Table 1 (NCA, 2014).

Table 1 Changes in temperature and related variables in the U.S. and regions in Florida (USFWS, Personal communication, 2017).

Temperatures Since 1895	U.S.	+1.3° to +1.9°C
Temperatures Since 1991	Florida Panhandle	-.5° to +.5°C
	Northern Florida	+.5° to 1.0°C
	Central Florida	+1.0° to 1.5°C

	South Florida	Greater than 1.5°C
Temperatures by 2100	Statewide	+3.0° to +7°C
Projected Increase in Extreme Heat Events	Statewide	+4.0° to +8.0°C
Increased Days over 35°C	Western Florida	Greater than +50 days
	Interior Florida	+40 to +50 days
	Eastern Florida	+30 to +40 days

The Atlantic sea surface temperature (SST) patterns greatly affect the precipitation of neighboring land masses and climate patterns (Moses et al., 2013) Since the atmosphere is warming it has the ability to hold more water, thus increasing the chance for more intense and heavy downpours with longer dry periods in between (Irizarry-Ortiz et al., 2013). Florida has a mean annual rainfall of 137 cm but in the panhandle and southeast coast have an annual rainfall exceeding 165 cm (Park et al., 2011). In central and south Florida, about two-thirds of the precipitation falls during the wet season, which usually starts in June and ends in October. Coastal areas of Florida have an afternoon onshore sea breeze that develops because of different latent heat capacities of land and ocean masses affecting the moderating of temperatures and causes wet sea precipitation (Irizarry-Ortiz et al., 2013). NCA (2014) reports that average precipitation has increased by +5 to +10% since 1900 in South Florida and 0 to +5% in northeastern Florida as shown in Table 2. However, in central Florida and the panhandle, precipitation has decreased by -5 to -10%. Florida has seen an increase in heavy downpours over the last 30-50 years. Many models indicate in future precipitation projections an increase in the wet season leading to more flooding and massive shifts in the frequency and intensity of these flooding events (NCA, 2014).

Table 2 Rainfall trends in regions of Florida (USFWS, Personal contact, 2017)

Rainfall Amounts Since 1900	Florida Panhandle	-5 to -10% of average
	Northern Florida	0 to +5% of average
	Central Florida	-5 to -10% of average

	South Florida	+5 to +10% of average
Increased Heavy Downpours since the 1970s	Statewide	+27%
Increased Annual Rainfall by 2100	Statewide	0 to +20%
Increased Dry Consecutive Days by 2100	Statewide	-10 to 20%
	South Florida	0 to +30%

Dry consecutive days are projected to increase by 10 to 20% for most of Florida and potentially up to 30% for South Florida. Extended periods of high temperatures along with longer droughts are driving wildfires. The majority of lightning-caused fires in this region occur between May and September, with larger fires in the early part of the wet season. The shortest fire interval could be 2 to 3 years and the longest interval 10 to 15 years. Wildfires can cause changes in tree density, changes in species composition and decreased carbon storage capacity (U. S. Fish and Wildlife Service, 2006).

Hurricane activity usually occurs over the oceans in areas where SSTs exceed 26°C. A factor in the year-to-year variability of these hurricanes is El Nino: Atlantic hurricanes are suppressed when an El Nino is under way in the Pacific. There is a nonlinear upward trend of SSTs over the 20th century due to global warming and human activities. There has been a decrease in vertical wind shear over the central North Atlantic, which sometimes prohibits the vortex from forming. Higher SSTs correlate with an increase in water vapor in the lower troposphere. Since 1988, the amount of total column water vapor over the global oceans has increased by 1.3% per decade (Trenberth, 2005).

2.3 SPECIES SPECIFIC HAZARDS

Loggerhead Sea Turtles and Southeastern Beach Mice are very different species but they share the same ecosystem for parts of their life cycles and therefore are exposed to the same hazards. These shared hazards are mostly caused by anthropogenic factors, habitat destruction by storms or human developments, sea level rise, climate change, and intense predation. Anthropogenic impact, such as sea walls, light pollution, and coastal development have proven more harmful than others. This past year coastal homes in Southeastern Florida's real estate market were estimated at $15 billion to $36 billion dollars that will ultimately be lost due to sea level rise (Bolstad, 2016). Dunes are lost during the construction of these mass real estate plots which are homes to beach mice and provide surface area of beach for the loggerheads to nest. Hurricanes and sea level rise also pose a threat to the species habitat. Rising sea levels will also be accompanied by higher wave run-up during storms, which will likely increase mortality of sea turtle eggs laid in low-lying areas by drowning a portion of the incubating eggs (National Wildlife Federation, 2017). The primary habitat of the beach mice, dunes covered with vegetation, will be washed away by increase in sea level and frequent hurricanes. Sea oats within the dune grasses will be destroyed and washed away, leaving the mice to scavenge for other foods or move on to a different area (Bird et al., 2016). The exposure to man-made light, such as street lamps and other man-made sources of light, is extremely dangerous for sea turtle hatchlings and can often make them disoriented. Studies showed that because light levels influence predation risk in many species, behavioral responses to artificial light for beach mice are likely to be common across all species and subspecies (Miller et al., 2004). Because of the high predation rate of these mice and their average lifespan of six months to one year, they cannot reproduce quickly enough to yield a large population. These mice reach sexual maturity at six weeks but are among the only 3% of mammals that are monogamous and will not reproduce as often (Bird et al., 2016). Loggerhead turtles have a variety of unique hazards such as tumors caused by papillomavirus, boating and bycatching, and shift in ocean currents. Sea turtles use ocean currents to travel and find prey. Due to climate change, the ocean currents temperature, direction, and nutritional contents are shifting. These factors can potentially interfere with the turtles site fidelity; making them change course and also creating more challenges for finding food (SEE Turtles, 2017). More southern turtles species can be "turned around" and found in northern locations not natural to them and well outside of their normal range (SEE Turtles, 2017). These hazards are extremely important to consider when making an adaptation plan that could assist in mitigating these issues.

3 VULNERABILITIES

3.1 COASTAL ECOSYSTEMS AND SEA LEVEL RISE

When discussing the vulnerabilities of Florida's coastal ecosystems, it is necessary to delineate the precise reasons why the coast is so vulnerable to inundation. Ultimately, the coastal area's low lying topography is the primary reason why the ecosystems of the barrier islands and beaches of Florida's eastern coast are so susceptible to sea-level rise. Florida is also experiencing land subsidence which is happening in conjunction with sea-level rise exacerbating its effects and intensifying the severity of the hazards it is associated with. Subsidence is the phenomenon by which the land is slowly sinking in elevation over a long period of time. In the Everglades a study concluded that as much as two-thirds of the total volume of peat soil present in the area was lost due to anthropogenic activity and development (Aich et al., 2013). This directly resulted in a net amount of 2m of land subsidence on average (Aich et al., 2013). The second principle reason for the vulnerability of the coast is that the rate at which sea-level rise is occurring is outpacing the coast's natural ability to migrate landward. The plants and coastal ecosystems of today's Florida cannot continue exist as they currently do in the face of sea-level rise. Human interference has impeded their ability to adapt. This directly leads to the last reason why the coast is vulnerable, which is that some ecosystems and habitats are sandwiched on beaches between the encroaching ocean and anthropogenic development.

In a study conducted in 2000, the scientist Asbury H. Sallenger Jr. took a look at two barrier island systems, one on the east coast of the United States and one on the Gulf of Mexico coast and compartmentalized the reactions barrier islands can have to storm surges. The results of this study depicted that depending on the severity of the storm in conjunction with sea-level rise, the barrier island in question would respond differently. Sallenger Jr. also found that the relationship between barrier islands, sea-level rise, and storm surges were very dynamic because when a barrier island experiences a storm it is effectively transformed and thus its response is changed as well. One such example is Isles Dernieres which commonly fell into the swash regime. However after a storm the barrier island more so resembled a collision regime (Sallenger Jr., 2000). When a barrier island experiences a storm surge and wave runup, inlets can form on its coast and thus affect the overall response and impact of the barrier island and storm respectively. Sallenger Jr. delineated four different regimes that a barrier island could fall under by breaking down the geography of the beach itself into the dune base height, dune crest height, and low elevation of swash impact and high elevation of swash impact height.

These regimes include:

- Swash Regime;
- Collision Regime;
- Overwash Regime;
- Inundation Regime.

A barrier island's placement into one of these regimes is dependent upon the geometry of the barrier islands beaches, the severity of the storm, and the sea-level rise that the barrier island is experiencing. All of these regimes besides the swash regime result in a net loss of sand found on the beaches of the barrier island that experiences a storm surge. In an overwash regime the sand and sediment lost is typically transported away from the beach about 100 kilometers away and it is this regime that causes the barrier island to slowly migrate landward. In an inundation regime, which is the least understood regime, it has been observed that sand and sediment of a barrier island that falls into this regime is deposited away from the beach of origin on the order of thousands of kilometers (Sallenger Jr., 2000). As the name implies an inundation regime results in a barrier island being completely covered with water and its habitats and local populations being irreversibly impacted. Sea-level rise exacerbates and intensifies the effect storm surges have on barrier islands as they decrease the distance between the ocean surface and the dune crests. As for Pelican Island it is increasingly likely that it will fall into the inundation regime in the coming future should adaptation strategies not be crafted/continue to be implemented to mitigate the impact storm surges will have on the area.

3.2 ECOSYSTEMS AND CLIMATE CHANGE

3.2.1 System Vulnerabilities

The habitats within South Florida are reliant on many abiotic factors that directly relate to climate conditions. As discussed previously, many hazards are imposed on the South Florida systems; however, it is important to understand why these are hazards. In this section the vulnerabilities of habitats within South Florida will be discussed to better understand why certain hazards due to climate change are so impactful.

Seasonal abundance of freshwater in South Florida has caused the development of aquatic and terrestrial systems (McPherson et al., 1976). Each system is controlled, in part, by the moisture in the soil or by the duration and the depth of inundation. The amount and residency of moisture within the soil is determined by the amounts and frequency of rainfall, the infiltration capacity of the soil itself, underlying bedrock, and the land elevation. High elevation areas that are rarely flooded usually support pine forests, hardwood hammock forests, or grassland systems. Low elevation areas that are flooded part of the year are largely made up of wetlands, such as prairies, marshes, or swamp systems.

Water, sunlight, and nutrients are essential ingredients for organic plant production, which sustains each system (McPherson et al., 1976). Marsh and swamp systems require seasonal flooding to maintain adequate levels of production. Terrestrial plants, which do not tolerate much flooding, rely mainly on rainfall and soil moisture. Plant production sustains each system by providing the food for the two other major components of a system: the animals and the saprophytes (bacteria, yeast, fungi).

Many plants and animals are adapted to and dependent on the seasonal fluctuations of water level. During wet seasons, aquatic-plant production abounds; small crustaceans and fish feed on the growing plants or plant remains (McPherson et al., 1976). With abundant food and space, aquatic-animal populations increase. As water levels decline during the dry season, the small aquatic animals are forced to concentrate in scattered ponds, tributary creeks, and sloughs. The concentrated biomass then becomes a rich source of food for larger fish, alligators, snakes, local and migratory birds, and mammals.

Rainfall is the ultimate source of water in South Florida. It is maximal over the Atlantic Coastal Ridge (~1,500 mm/yr) and decreases incrementally away from the ridge (McPherson et al., 1976). The annual rainfall pattern, however, does not correlate with the physiographic regions and their ecological systems. These regions and systems are more closely correlated with the distribution of water, soil type, and land elevation.

Therefore, changes in rainfall, soil moisture, seasonal water level, amount of sunlight, and nutrient availability will drastically impact the South Florida ecosystem and the habitats within them. Changes in precipitation and soil moisture will cause changes in the distribution of habitats that rely on high or low soil moisture. This could cause arid habitats or wetlands to overtake the other depending on the increase or decrease of precipitation. Furthermore, changes in distribution of the various habitats will also affect the species within them. Unless there is a balance between the abundance of each habitat, the increase of some habitats compared to others will cause a reduction in biodiversity. This cause holds true with climate changes that directly affect the habitats that depend on specific parameters, such as changes in seasonal water level, amount of sunlight, and nutrient availability as previously mentioned.

Under ideal conditions, systems undergo orderly, successional changes until a relatively stable situation is reached in which a system is in equilibrium with its climatic environment and is capable of self-perpetuation if the climate does not change radically (McPherson et al., 1976). The stable system is at climax. Those systems that are unable to reach complete stability are considered to be at subclimax. Each system in this successional change has its own species, organization, and conditions, and these are different from all others. In addition, each system creates the habitat and conditions for its successor.

In South Florida, rainfall is generally adequate to allow native plants to follow their characteristic successional patterns, but droughts have regularly stressed vegetation and altered this process. The plant systems have evolved in this pattern and are adapted to seasonal changes in water depth. Because of droughts, fires, and more recently, man's intrusions, systems seldom reach climax; most are limited in their development and are subclimax. In addition, the alterations imposed by man, such as the introduction of exotic plants, appear to have set in motion changes in the make-up and process of this succession.

Fire is an important factor that keeps low successional habitats in check due to its effect on freshwater and terrestrial systems (McPherson et al., 1976). It maintains some systems, such as pine forests or sawgrass marshes, and limits others, such as hardwood forests. Lightning is the most common cause of wildfires during the summer thunderstorms, but during the wet season wildfires tend to be less severe than fires during the dry season because the moisture protects roots and soil. During the dry season, fires often burn into the roots and soil, killing even fire-resistant species.

Furthermore, South Florida's systems have both tropical and temperate components (McPherson et al., 1976). Land animals are almost completely temperate-zone species, but the plants are derived from both zones. Temperature largely affects the plants found in South Florida. High temperatures restrict the southward migration of temperate plants, and low temperatures restrict the northward migration of tropical species. Tropical plant species are frost sensitive and some defoliate after exposure to 7° C (45 ° F). Damage increases with duration of cold. Temperature is variable with soil type, water conditions, and land altitudes. Areas of sandy soils tend to be warmer than areas of muck. Water moderates air temperature: therefore, swamps and marshes tend to be warmer in the winter and cooler in the summer than forest and prairies.

Hurricanes and tropical storms affect ecosystems through their local and immediate destruction and through their more extensive and long-term alterations such as salting of land by tidal flooding and changing of coastal elevations and outlines (McPherson et al., 1976). Coastal ecosystems are more susceptible to these changes than interior systems.

Water is the medium that links coastal ecosystems within the South Florida coastline, such as ecological areas, including sandy beaches, mangroves and salt marshes, shallow bays, and the Florida Reef Tract (McPherson et al., 1976). Saltwater from offshore currents moves over the reef tract, through the bays and mangroves, and back offshore, carrying physical and biological products from one coastal environment to another. Freshwater, moving overland from the mainland through the mangroves and into the bays and out to sea, transports terrestrial products to marine habitats. Where moving water acquires sufficiently different characteristics, it supports different plant and animal communities.

The Florida Current, moving around the tip of Florida and continuing northward as the Gulf Stream, provides clean, warm, saline water to the coastal area; water that helps produce the conditions required for coral formation and that supports a diverse tropical marine flora and fauna. In addition, the Florida Current transports and distributes juvenile fish and invertebrates, such as plankton, to coastal water.

Tidal currents flush oceanic water in and out of the bays, mixing it with fresh water from rains and terrestrial runoff. The sediments and shallowness of the bays encourage the growth of extensive marine grass beds. These grass beds are highly diverse and productive habitats adapted to some fluctuation in salinity and temperature. The bays themselves derive some of their nourishment from the mangrove and salt marshes and tidal flushing and terrestrial runoff.

Any major change in the coastal environment will have an effect throughout the coastal ecosystem. Diminishing nutrient production in one part of the system will show up as less biological production in another part, and disturbed sediments are often redistributed, smothering a distant habitat. In addition, alteration of freshwater runoff changes the distribution of coastal salinity. These changes affect coastal habitat distribution and quality, and, as previously stated, if there is a reduction in habitat availability, there will be a reduction in biodiversity.

3.2.2 Habitat Vulnerabilities

Within the South Florida region, two refuges were analyzed specifically. Pelican Island and Lake Wales Ridge National Refuges will be focused on for the remainder of the vulnerability section. Pinewood flats and scrub habitats are two of the most abundant habitats in the Lake Wales Ridge National Refuge. When evaluating ecosystem services, mangroves, seagrass beds, and oyster beds are some of the most influential habitats within Pelican Island National Refuge.

Pinewood flat habitats are characterized by rocky outcrops and sandy flatlands, open canopies of slash pine, a dense understory of low shrubs and grasses, and high elevation which causes these habitats to be rarely flooded. Pinewood flats require wildfires to reduce the succession of hardwood trees that would otherwise take over the habitat. If there is increased precipitation, this will cause a reduction in wildfires needed to sustain the pinewood flat habitat. A reduction in wildfires will cause a reduced distribution of longleaf pine due to decreased germination. Furthermore, a reduction in wildfires in the wet season increases the amount of competing hardwoods and dry, burnable litter that can cause a severe fire during the dry season. Therefore, if there is an increase in precipitation, there will be decreased pine flatwood habitat (Figure 3).

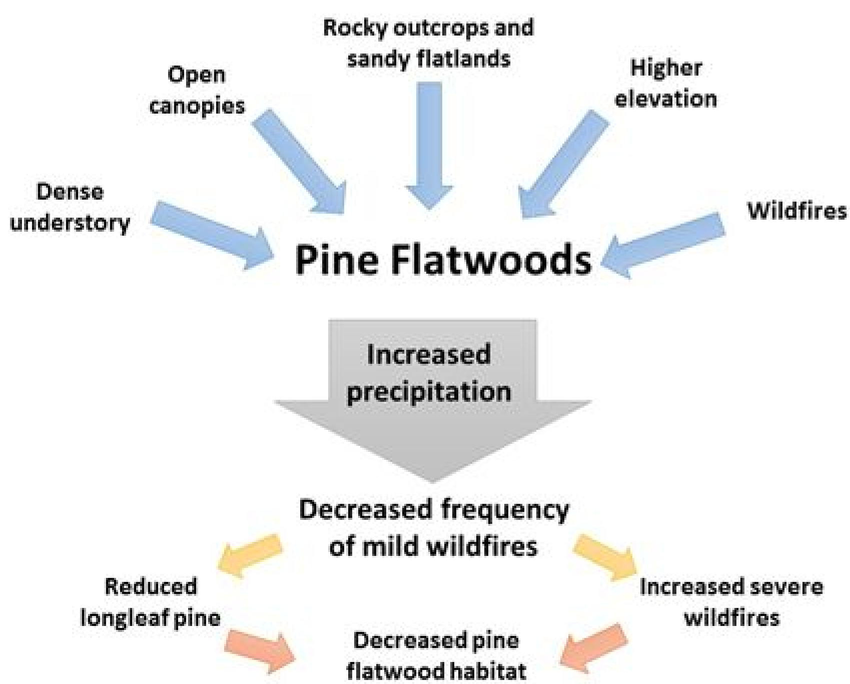

Figure 3: Pine flatwoods vulnerability flowchart

Scrub habitat is characterized by low-nutrient sandy soils, an abundance of shrubs and xeromorphic plants, and high summer temperatures due to a sparse canopy. Scrub habitats vary because they are a transition habitat from the beach to the dominant type of inland vegetation to the specific area. Scrub habitat also requires wildfires to reset plant growth, keeping the habitat in an early successional stage. Increased precipitation would cause decreased amounts of wildfire; therefore, increased precipitation will cause a reduction in early successional habitats necessary for species' survival within scrub habitats (Figure 4).

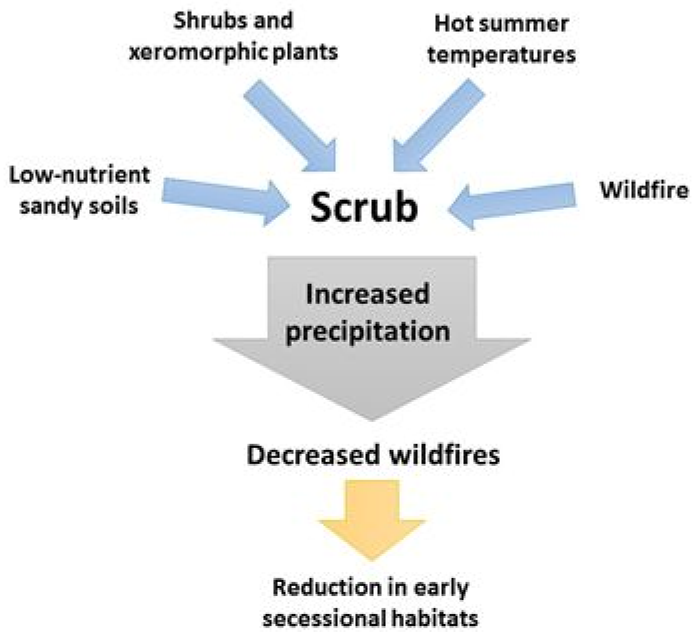

Figure 4: Scrub vulnerability flowchart

Mangrove habitats are characterized by a tropical climate, slow-moving waters with fine sediments accumulation, low-oxygen soil, large amounts of freshwater runoff, and seasonally reduced salinity. Mangrove forests can be found in deep estuaries, freshwater marshes, riverbanks, tributaries, island coastlines, freshwater swamps, and mangrove flats. Mangroves are largely formed and distributed by tidal inundation and storms. Hurricanes and other severe storms as well as snap freezes drastically reduce the abundance and distribution of mangroves. This causes a loss of ecological services such as decreased water quality, decreased coastal protection during tropical storms, and a reduction of habitat for fish nurseries and small animals (refer to figure 5).

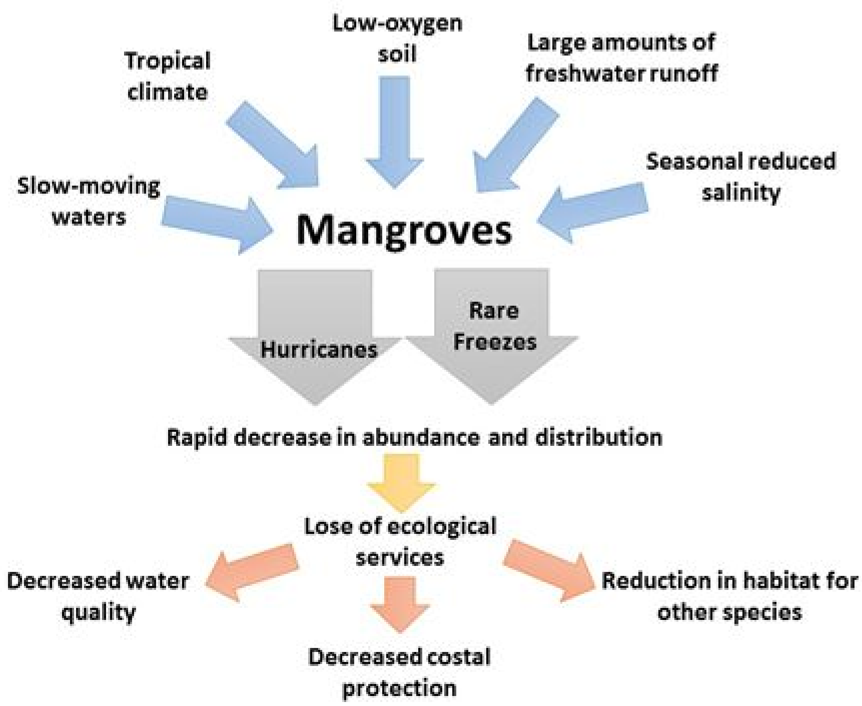

Figure 5: Mangrove vulnerability flowchart

Seagrass bed habitats are characterized by shallow depths, high light levels, and salty and/or brackish waters. Snap freezes cause high fish mortality, which results in algal blooms. Hurricanes and other severe weather cause sedimentation. Both algal blooms and sedimentation cause decreased light penetration, which then results in decreased water quality due to loose sediment, decreased habitat for adult and juvenile species, and decreased food sources for macrofauna (Figure 6).

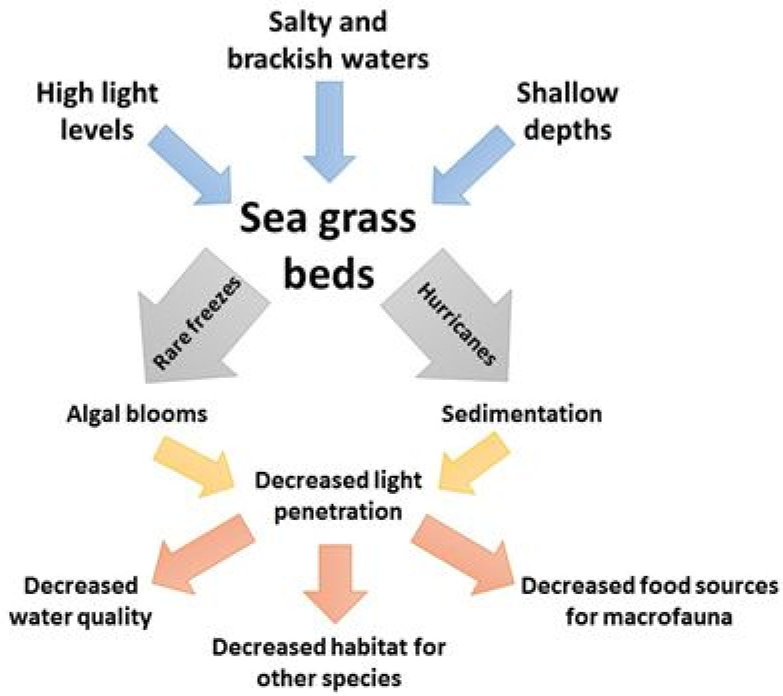

Figure 6: Seagrass vulnerability flowchart

Oyster bed habitats are characterized by brackish water, less than 10 meters deep, and a pH of 8.1. They commonly occur in estuarine river mouths and along coastlines. Ocean acidification could lead to shells (made mostly of calcium carbonate) being dissolved in adult oysters and larval shells being prevented from forming. Continuing ocean acidification would cause decreased population sizes of oysters, which would result in decreased water quality, a loss of habitat and refugia for other adult and juvenile species, and a loss of shoreline stabilization due to increased sediment deposition and wave energy (Figure 7).

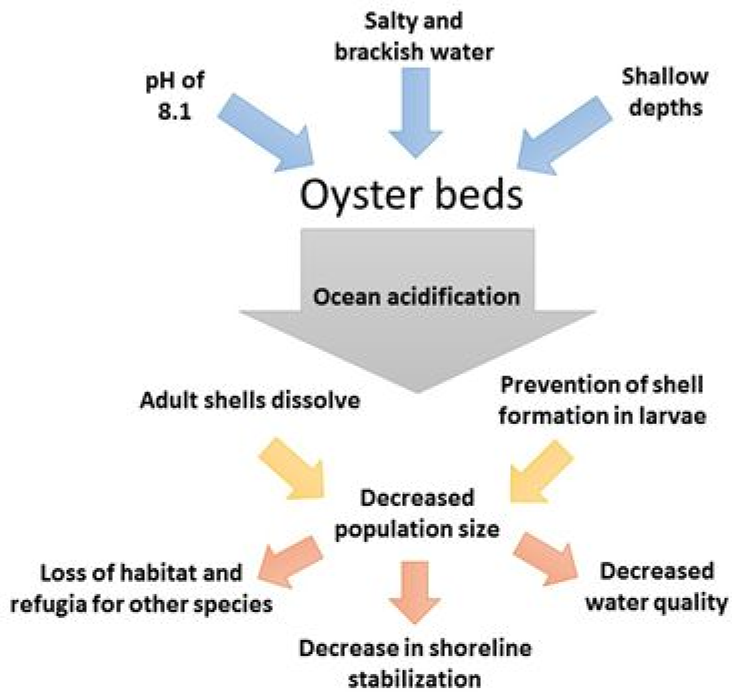

Figure 7: Oyster vulnerability flowchart

Fully understanding the vulnerabilities of a system is crucial in having a comprehensive knowledge of its inner workings. An understanding of a system's vulnerabilities allows added foreseeability in situations that would not otherwise be apparent when only assessing the hazards a system is exposed to. Furthermore, vulnerability understanding improves estimations when modeling possible future outcomes and developing viable options and recommendations for adapting to and mitigating of possible undesired future circumstances.

3.3 VULNERABILITIES OF LOGGERHEAD SEA TURTLES AND BEACH MICE

The Loggerhead sea turtles and Southeastern Beach Mice have similar vulnerabilities due to being a part of the same ecosystem. Human induced pollution, reduction of the nesting habitats, and lack of defense mechanisms are vulnerabilities that these neighbors share. Plastic in the oceans can be misconstrued as a jellyfish for Loggerheads and it is estimated that more than 100 million marine animals are killed each year due to plastic debris in the ocean including the Loggerhead. More than 80% of this plastic comes from land and is run off through rivers and streams and carried into the ocean (Sea Turtle Conservancy, 2017). Because pollutants are mostly from land or found on land, this is also an issue for the beach mice. Loggerhead hatchlings and small Southeastern Beach Mice have a lack of self-defense. Because these animals are so small and vulnerable, they lack appropriate predator recognition and avoidance mechanisms, which makes them highly vulnerable to predation by large birds, domestic dogs and cats, and other beach dwellers such as foxes and skunks (Bird et al., 2016). Vulnerabilities specific to the Loggerhead include anthropogenic threats combined with the impacts of sand temperature increase, food decrease due to ocean acidification, and stress-induced papilloma virus (Fisher et al., 2014). Temperatures at many nesting beaches worldwide have already been warming, for example in the Caribbean, South Atlantic, and Western Pacific. Due to temperature-dependent sex determination, the female to male sex ratio in the population is increasing and may eventually approach 100% female (Fisher et al., 2014). In the long term it will lead to the crash in reproductive success due to lack of males. In more extreme cases, hot beach sand temperatures could cause egg mortality (Fisher et al., 2014). The turtle hatchlings are led to the ocean by light sources and move in disorientated, circular paths until they find the water. Evidence suggested that prohibition of beach lighting during nesting season substantially reduced disruption of loggerhead turtle hatchlings (Witherington et al., 1991). It is believed that loggerhead turtles see poorly in the red area of the spectrum, and have been observed to retain a seaward orientation despite the presence of light emitting primarily long-wavelength light (Witherington et al., 1991). Climate change will be accompanied by higher wave run-up during storms that will likely increase mortality by drowning of sea turtle eggs and beach mice burrows in low-lying areas (Lohmann et al., 2012). The issue of deteriorating beaches due to sea level rise can make the turtles site fidelity an important vulnerability. The site fidelity means that the sea turtles will reach sexual maturity in about 20-30 years and then return to the same beach where they were born. Studies have shown that this is achieved by the turtles using Earth's magnetic field which points them in the directions they need to go (Figure 8; Lohmann et al., 2012). With the rapid increase in sea level, the highly used nesting beaches, such as Archie Carr in Southeastern Florida, are in extreme danger of being non-existent within the next 10-15 years (Lohmann et al., 2012).

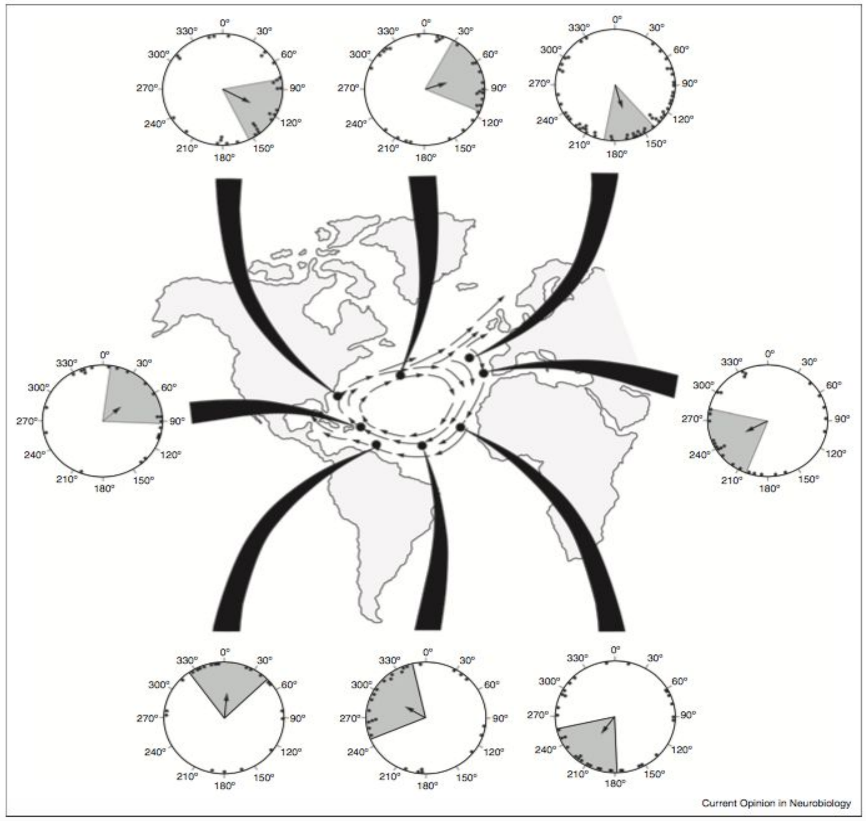

Figure 8: Magnetic field projection showing the oceanic routes taken by sea turtles (from Lohmann, Lohmann, & Putman, 2012).

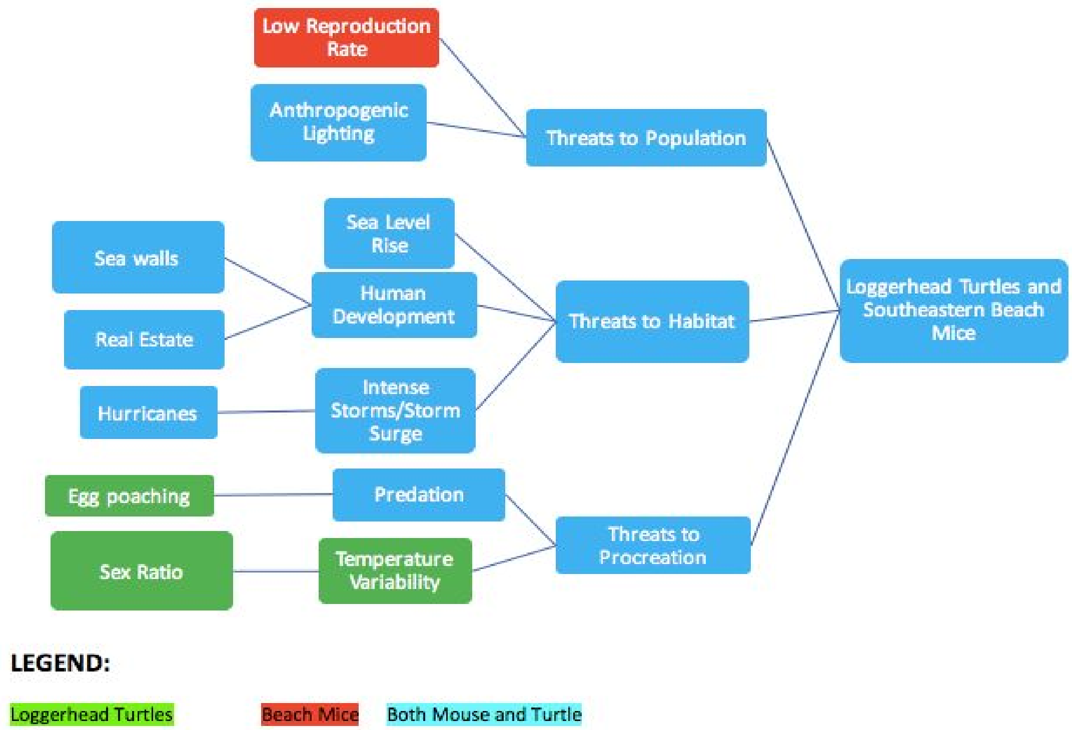

Figure 9: HAzards and vulnerabilities of Loggerhead turtles and Beach mice.

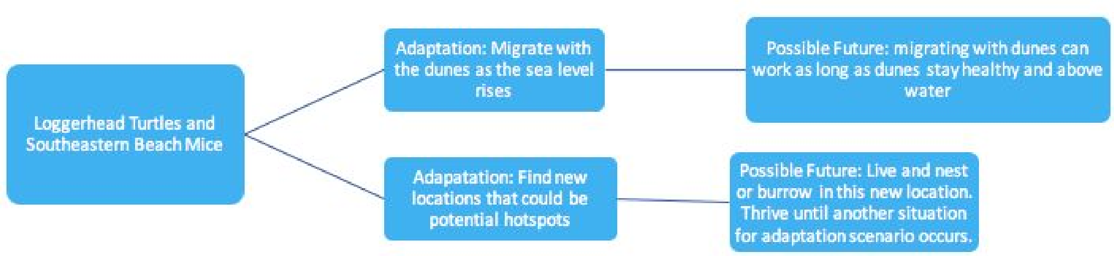

Figure 10: Adaptation Possibilities as well as possible outcomes for the future of the Loggerhead Turtle and Southeastern Beach Mice.

4 FORESIGHT

4.1 SEA LEVEL RISE

Understanding both past and present hazards and vulnerabilities that the Pelican Island and the surrounding barrier island systems face will be crucial in the evaluation of possible sea-level rise scenarios and the effects of sea-level rise on ecosystem and habitat migration, land movement, and anthropogenic concerns. While we can no longer consider the past as an analog of the unpredictable future ahead, analyzing all data, past, present, and future, will be key to developing foresight that can guide the implementation of practices that can safeguard the coastal ecosystems.

NOAA's most recent global mean sea level rise scenarios now project an increase of up to 2.5m by the end of this century. With a high confidence, 90% conditional probability, it is highly likely that these projections could be seen long before 2100 (NOAA, 2017).

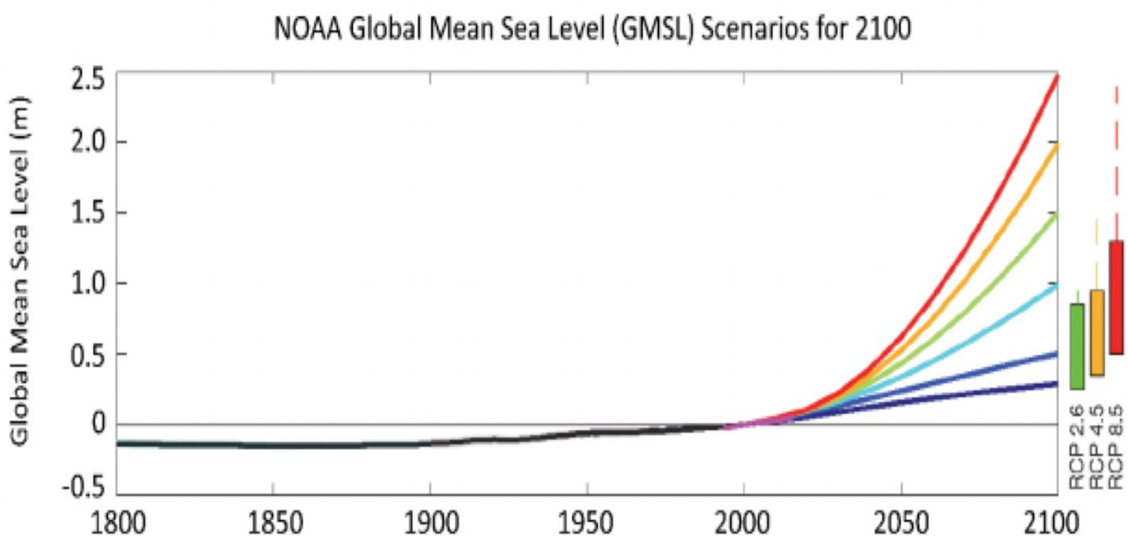

Figure 11: Global Mean Sea Level Rise Scenarios for 2100 (NOAA)

The lowest scenario is based on historical data; as the scenarios increase in magnitude, factors such as ocean and atmospheric warming, and ice sheet loss, are incorporated into predicting the rate and amount of sea level rise we may potentially see. Predictions after the year 2100 have only recently been considered in these projections (NOAA). These predictions demonstrate a dramatic escalation proposing final global sea level rise, with only a 2°C increase in temperature, to be anywhere from 29-55 m or more over the next few centuries, on the extreme end of the spectrum (Sneed, 2017).

Local sea level rise can deviate significantly from the global average, and for Florida, it is projected to be 0.4-0.7 m higher than the global average predictions. Even so, these projections, both locally and globally, are conservative in nature. An influx of new evidence has increased the likelihood that a 2-5m increase by the end of this century cannot be excluded (NOAA). In forming future adaptation and mitigation plans, we consider accounting for the higher projections of sea level rise to be critical, in order to be prepared for the worst possible outcomes.

Regional and local vertical land movement and ocean dynamics play a key role in evaluating sea level change at a specific region and location, but barrier island movement and ecosystem accretion are currently outpaced by the rising seas (Parris et al., 2012). Figures 12 to 14 show the impact of sea level rise on Pelican Island and the barrier islands. These images of the affected areas as sea level increases only take into account the geometry of sea level rise, and do not consider the dynamics of the system as a whole.

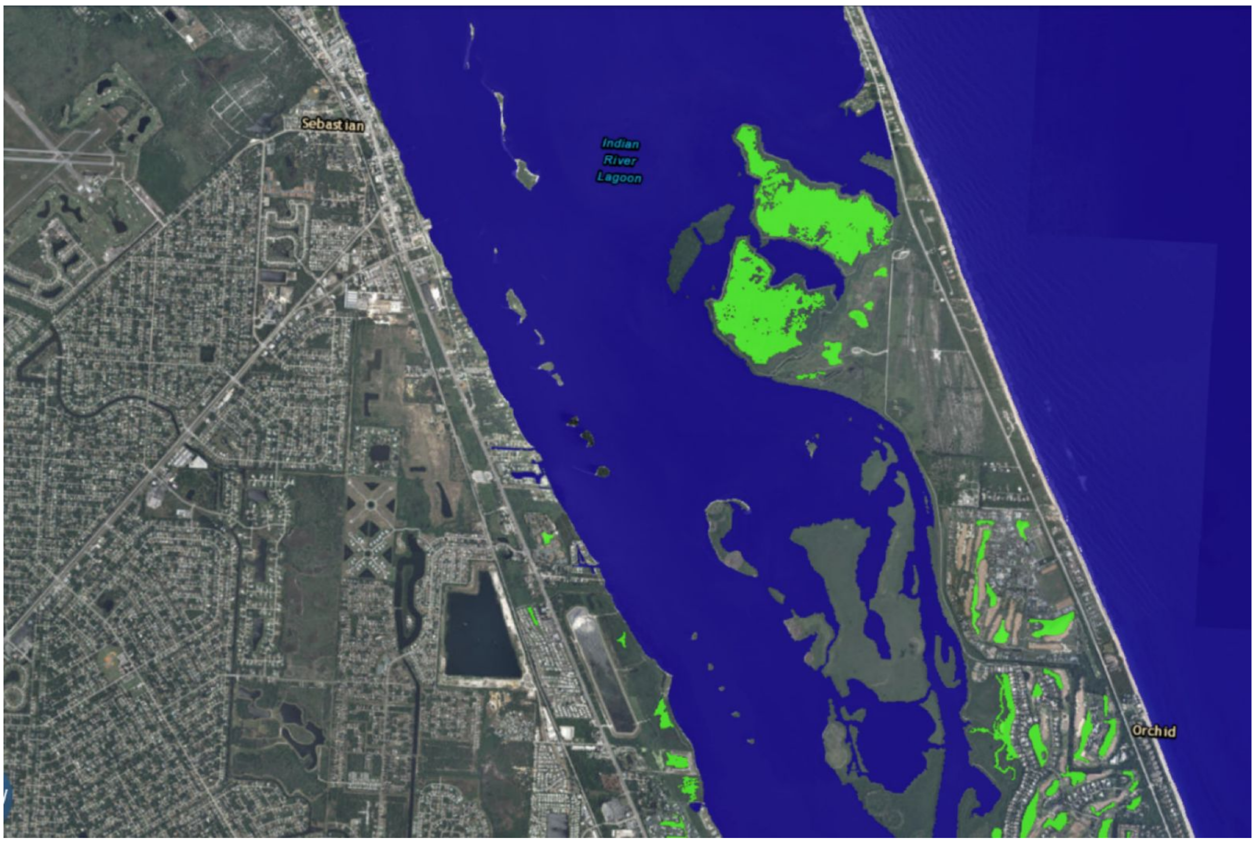

Figure 12: Current map of sea level of Pelican Island NWR and surrounding areas. Green is low-lying areas. Figure generated with NOAA's Sea Level Rise Viewer Tool

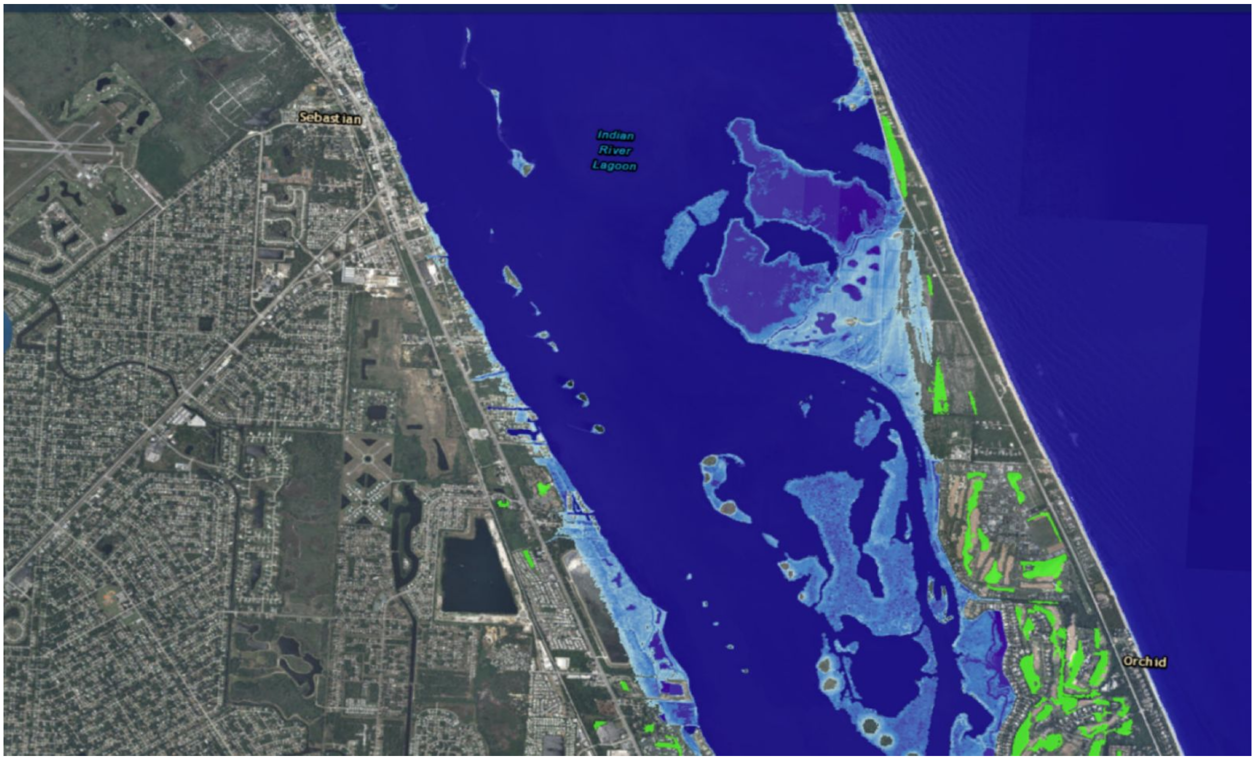

Figure 13: Pelican Island NWR and surrounding areas after 1m SLR. Source same as Figure 12.

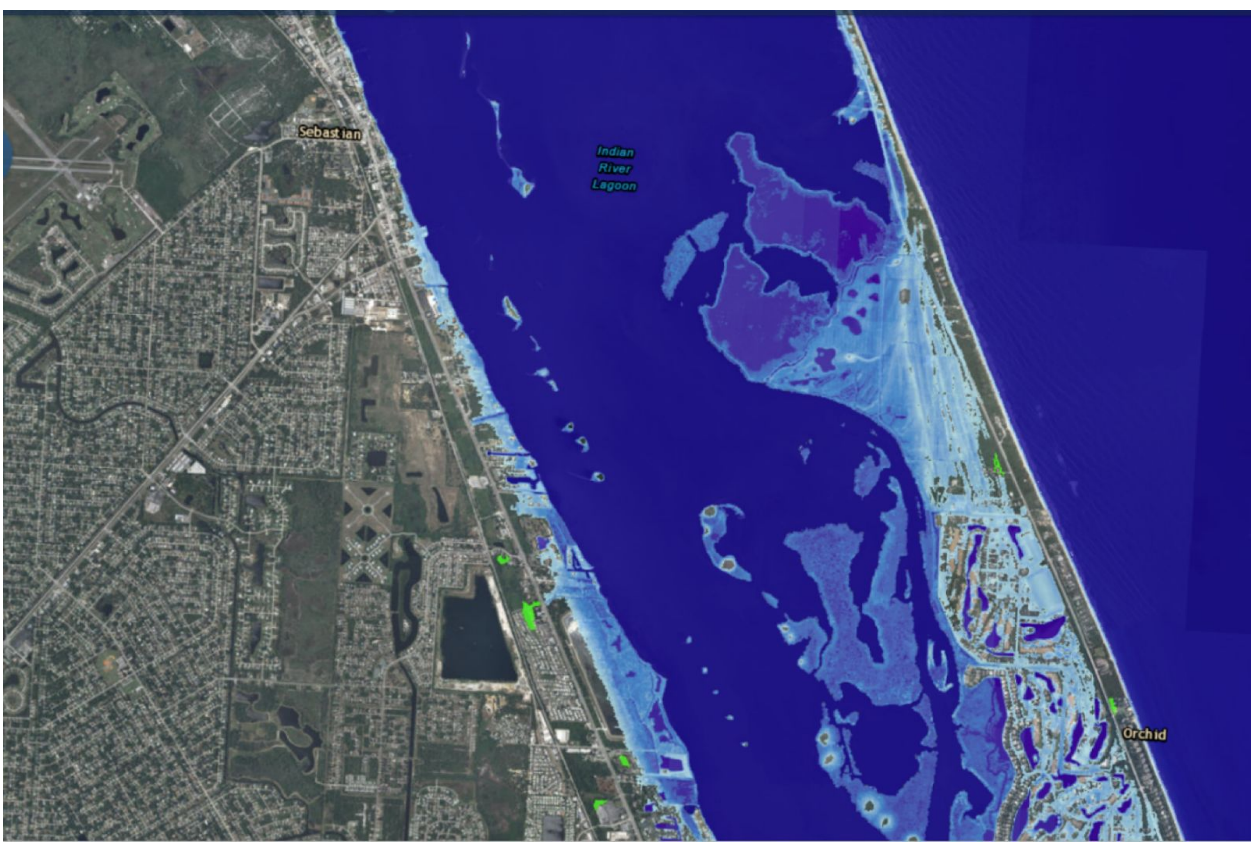

Figure 14: Pelican Island NWR and surrounding areas after 2m SLR. Source same as Figure 12.

As can be seen, Pelican Island NWR and the surrounding areas are severely decimated by only a few meters of sea level rise. Importantly, the influx of water occurs at the backside of the island system from the lagoon, instead of from the Atlantic Ocean on the opposite side. This poses unique challenges to mitigation and adaptation plans, as it may inhibit both island and ecosystem movement with the increasing distance between the islands and coastline. In effect, the likelihood of a complete loss of the barrier island system and the coastlines last defense from incoming storm surges and wave run-up is maximized.

Another important consideration of sea level rise in planning for the future is how the ecosystem landscape will change in response. As land is lost to rising sea levels, we see a dramatic shift in the acreage and diversity of ecosystems (Figures 15 and 17). Almost all of the freshwater and upland areas are converted to brackish/transitional, saltwater, and open ocean ecosystems. Again, these images only account for the geometry of the issue, and do not fully incorporate the dynamics of the barrier island system. Habitat losses and changes have the potential to be much more devastating than what is shown.

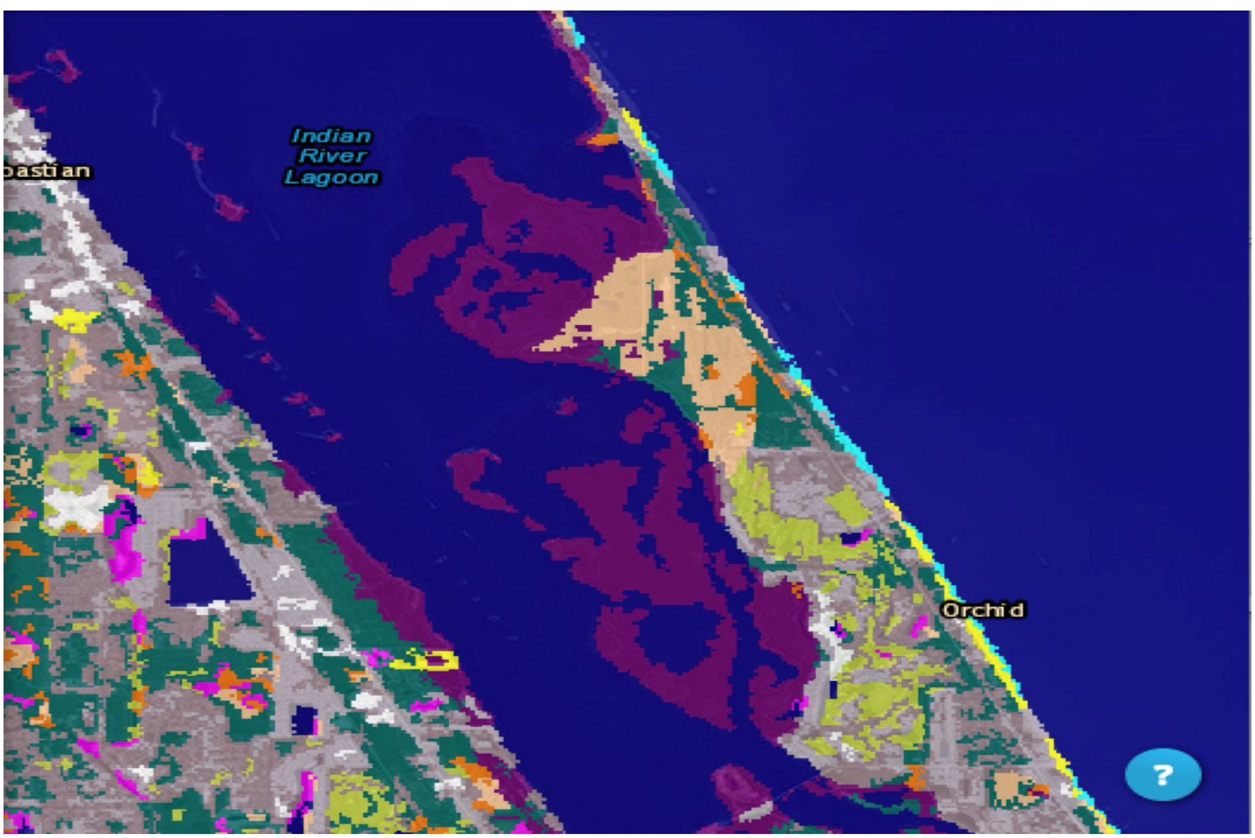

Figure 15: Current layout of ecosystems. Same sources as Figure 12

Figure 16: Ecosystem layout after 1m SLR. Same source as Figure 12

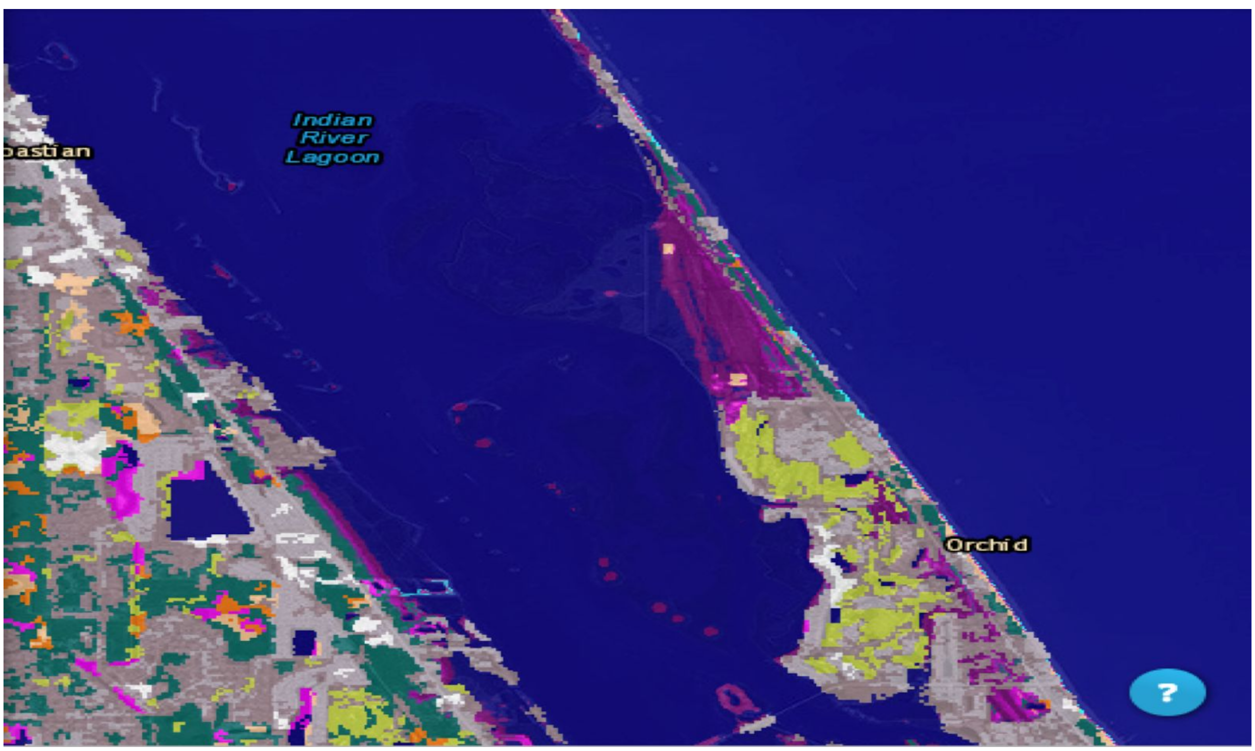

Figure 17: Ecosystem layout after 2m SLR. Same source as Figure 12

The maps and projections in Figures 12 to 17 present only a subset of the potential challenges we may face in the future. It is crucial to remember that the representations displayed here only consider sea level rise and ecosystem migration; they are absent of the other threats and considerations, such as anthropogenic influences and climate change, that need to be factored into the equation of our pending future. Despite the unpredictability of our path ahead, not all hope is lost. We have the ability, foresight, knowledge, and resources to aid these ecosystems in adapting to our changing environment.

4.2 CLIMATE CHANGE

Drought has become an increasing hazard for Florida. Establishing clear guidelines on how to mitigate the drought issue has been proven hard to accomplish. Dominant plant species can be vastly affected by droughts by changing genetic diversity and have serious consequences on ecosystems (Gitlin et al., 2006). Mortality rates with plant species will vary depending on the severity of the drought. Some plant species will die at slower rates if the drought isn't as severe or there could be rapid plant death rates if the drought is above average, which Florida has been experiencing (Gitlin et al., 2006). Dry seasons on Pelican Island and Merritt Island are crucial to ecosystems germination due to wildfires. The increase of temperatures and more frequent droughts are may increase the availability of fuels for more severe wildfires. Scrub on Merritt Island could suffer as temperature and humidity rise.

Surface temperature is forecasted to rise 4°C by 2100 in south Florida due to increased CO2 in the atmosphere. Cox et al. (2000) illustrate this with the model output displayed in Figure 18. The model output indicates a continuous temperature increase globally throughout the 21st century, with the increase over land being larger than the global average.

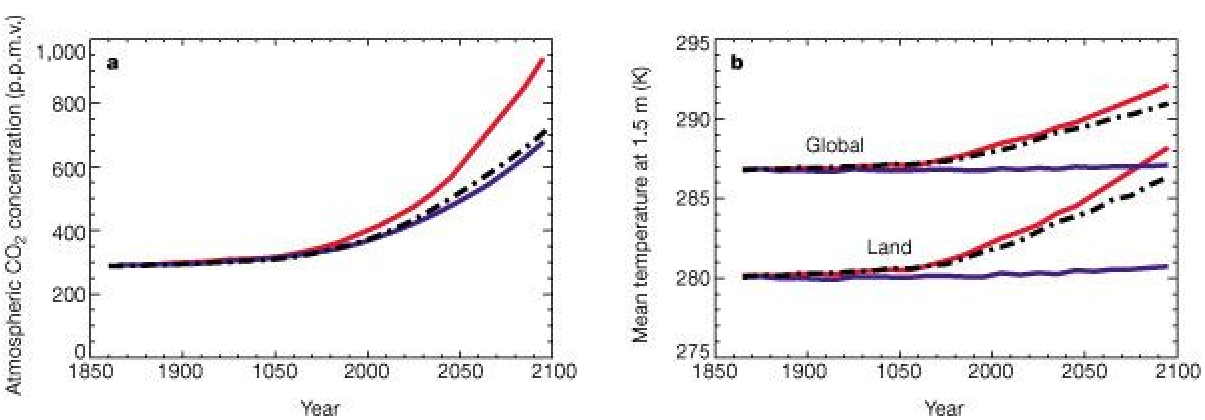

Figure 18: a. Atmospheric increase in CO2 ppm from 1850 to 2100. b. Mean temperature increase at a global level and at land level per year from 1850 to 2100 (Cox et al. 2000).

Increase of temperature is not the only variance that happens with the anticipated climate change. Changes in the Arctic Oscillation are creating abnormal drops in temperatures in southern Florida as well. The changes in the Arctic Oscillation are increasing snap freezes in areas, including south Florida, and that is creating harsh temperature fluctuations for ecosystems. Kennedy et al. (2014) explain that the polar vortex and Arctic Oscillation work together with high and low pressures creating drastic temperature variability. When low air pressure forms over the Arctic and high air pressure forms over mid latitude, fewer cold temperatures occur. When high air pressure forms over the Arctic and low air pressure forms over the mid latitude a weak polar vortex is created, pushing freezing polar air south (Kennedy et al., 2014). More frequent weaker polar vortices are forecasted due to more ice melting in the Arctic, bringing more snap freezes to south Florida. As strong polar winds blow on the eastern coast of Florida, an on-shore breeze brings the frigid air from the polar vortex and the west side will see less frigid air due to the on-shore breeze from the Gulf of Mexico. Differences in temperatures could get worse by 2100, impacting ecosystems on each side of southern Florida.

Florida has a wet season and a dry season each year. The dry season ranges from October-April and the wet season from May-October. Using data provided by the National Climatic Data Center in Asheville NC. aided in building the model shown in Figure 19. This model represents the precipitation during the dry season in Southern Florida from 1850 to 2017. Using the linear line equation allowed projections of precipitation to 2100, which indicates a continuous increase. With this increase of precipitation, the dry season in southern Florida could experience changes in consistency and/or duration.

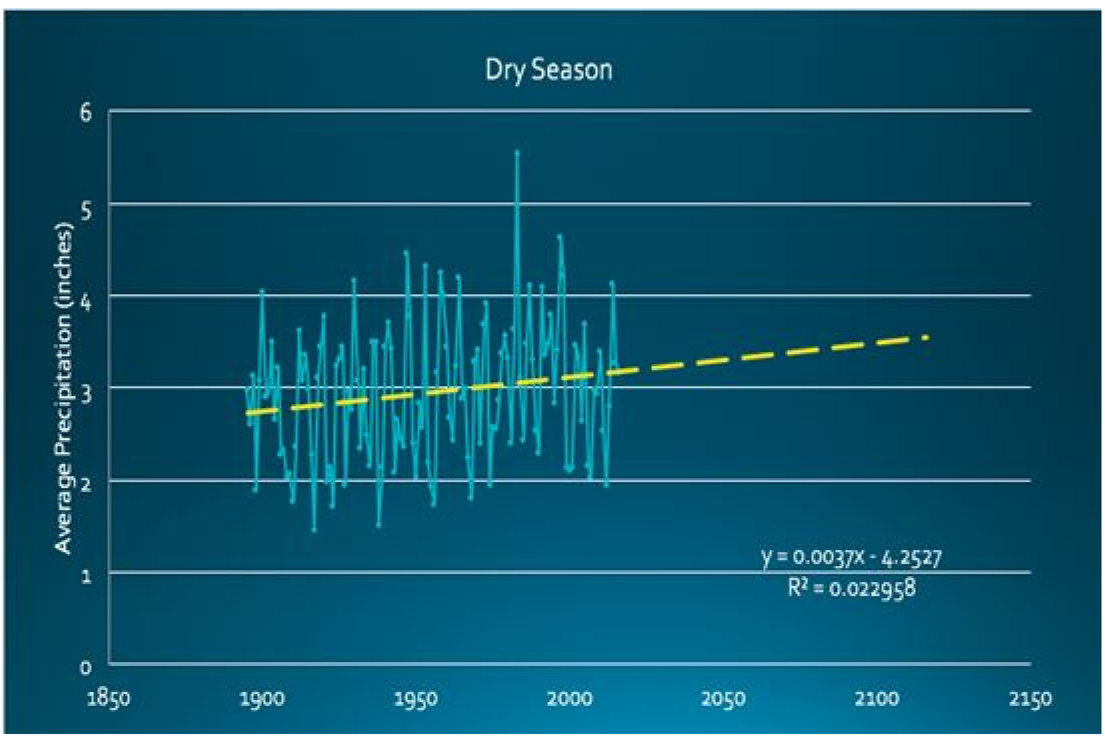

Figure 19: Average precipitation per month from 1850 to 2100 during the dry season in Southern Florida. Linear line shows an increase of precipitation during the dry season. Created from Florida Climate Center, Florida State University Center for Ocean-Atmospheric Prediction Studies.

As shown in Figure 20, the precipitation amounts in the wet season are projected to remain constant. These two models indicate that if the current climate trends continue with no change, Florida could have two wet seasons and two dry seasons per year. With these new amounts of precipitation, ecosystems on Pelican Island and Merritt Island would have to adapt, which could impact the species in the ecosystems.

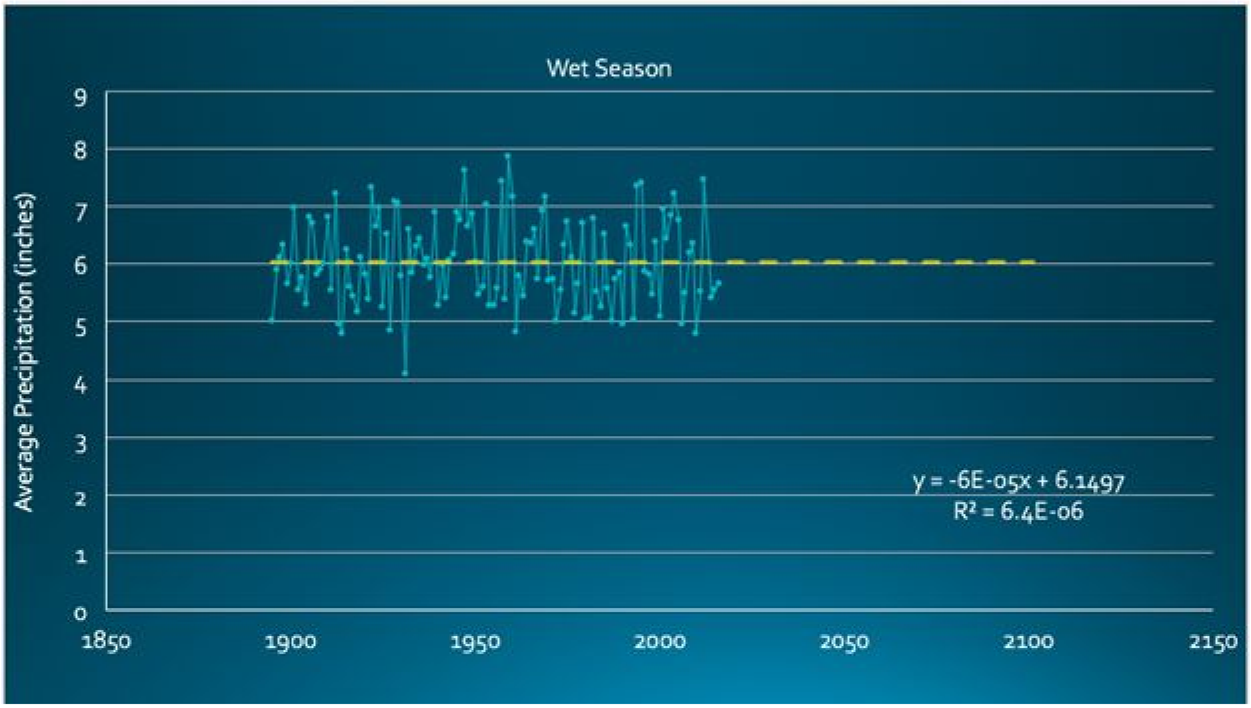

Figure 20: Average precipitation per month from 1850 to 2100 during the wet season in Southern Florida. The linear line shows consistent precipitation during the wet season. Created from Florida Climate Center, Florida State University Center for Ocean-Atmospheric Prediction Studies.

Ocean Acidification is rising due to increased amount of CO2 being absorbed by the oceans, which is leading to a decrease of pH (Feely et al., 2006). As acidification rates continue to rise oyster beds around Pelican Island could suffer. By 2100, pH levels could be as low as 7.85 and CO2 levels in the ocean could rise 10.7 ppm (Feely et al., 2006). Ocean acidic levels would cause acidosis, a carbonic acid accumulation in the species bodies, which leads to lower immune systems and reproductive difficulties. This could lead to a 10% decline of oysters in the next century, producing increased challenges in mitigating climate change impacts on Pelican Island.

4.3 SPECIES RELATED

In the realm of sustainability sciences, the subject of foresight is found to be most essential to any plan for adaptation or mitigation. The recognition of potential futures for a system under different scenarios allows the necessary time, space, and resource allocation needed to develop and implement contingency plans. It has often been the case in environmental management planning that long-term, more sustainable goals are given the back seat to more immediate yet temporary solutions. However, it is important to understand the need for both short-term and long-term planning when considering complex, dynamic systems, which are frequently changing as a result of natural variability in the environment and the impacts of anthropogenic activity. In doing so, we are better able to prepare for unpredictable or highly improbable situations in the future - more aptly referred to as Black Swans (Taleb, 2007). Regarding the futures of the aforementioned threatened and endangered species in the Southeastern region of Florida, appropriate foresight will be needed to successfully develop and implement sustainable recovery measures.

The ecosystem these species share provides much more than simple habitat; holding significant economic, ecologic, and historic value in society and the collective environment. By this measure, an appropriate level of priority can be assigned to aid in accelerating the planning process towards effective action.

It is broadly recognized that under current business as usual conditions, without proper adaptation, these species will sooner than later face extinction. Unfortunately, we are seeing environmental and anthropogenic change on a scale[HP1] …

In order to gain a sense of scale and more accurately identify possible futures, we must first look to modeling projections and simulations and then afterwards find room to imagine a scenario beyond that. The barrier islands of Southeastern Florida are subject to a wide range of hazards, which would affect their futures. Under climate change and increasing anthropogenic activity in the area, many of these hazards are subject to unpredictable change in severity relative to our current understanding of the systems involved. Such hazards include sea level rise, temperature variability, extreme weather events, shifting oceanic currents, and human development. To achieve a more accurate understanding of the possible futures, we will look at models of these hazards under best and worst-case scenarios with short-term and long-term perspectives.

4.3.1 Sea Level Rise

With an expansive low-lying topography, Florida has already experienced the effects of even small scale changes in sea level rise throughout the past several years (NOAA, 2017). Regarding the habitat range of the Southeastern Beach Mouse and nesting grounds of the Loggerhead Sea Turtle along the coastal barrier islands of Florida; current projections from multiple sources are expecting, by 2100, an increase in sea level on the order of 2 m in the area under the current worst-case scenario seen in Figure 21 (Lopez, 2015). The Loggerhead and the Beach Mouse will be unable to migrate or adapt quick enough to these changes in habitat. However, these projections are subject to change due to the high variability of such a dynamic system so it will be important to maintain multi-scenario based foresight in order to prepare for a range of possible future conditions of sea level which could potentially cause harm.

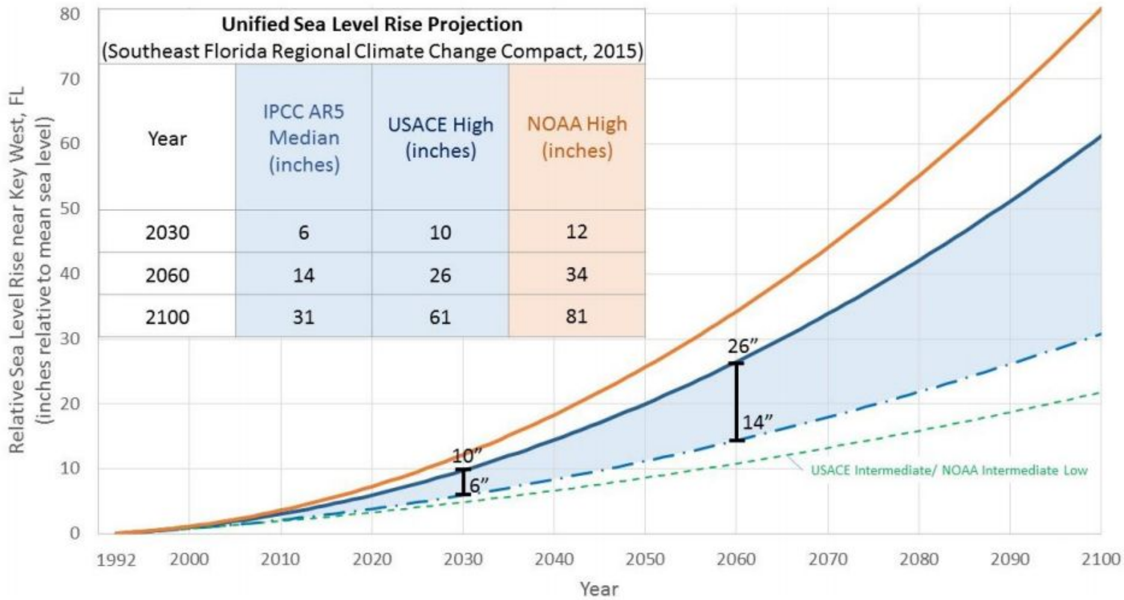

Figure 21: A unified sea level rise projection for Southeast Florida shows short term (2030) and long-term (2100) potential futures which could bring rapid, unwanted change to the area (Lopez, 2015).

4.3.2 Temperature Variability

Florida is projected to see temperature rise going forward as well. If temperatures continue along this trend, the state will see more hot days throughout the year. Additionally, cold snaps are projected to reach further south into Florida potentially affecting nests as well as juvenile sea turtles in the Indian River Lagoon. For the Loggerhead, this could become dangerous in terms of nest incubation as their sex ratios will be skewed altering their ability to reproduce at sustainable levels. In the worst-case scenario, we will see an increase in nest egg mortality rates and further decrease in the population of this species towards extinction. The Southeastern Beach Mouse will be less affected should these changes occur.

4.3.3 Gulf Stream Shifting

The Gulf Stream has been projected to shift particularly as a result of the ice sheet in Greenland melting and inserting large amounts of freshwater into the ocean. It is still unclear exactly how and when the ocean currents will be affected by this. However, there is evidence that sea turtles use the ocean currents to aid in their migration patterns. If the currents change, specifically the Gulf Stream, the ability of the turtles to navigate may be hindered, which could leave them stranded in the ocean or unable to return to their natal beach to lay their eggs. More research is needed to understand the connections between the Gulf Stream and sea turtle navigation.

4.3.4 Extreme Weather Patterns

Hurricanes, tropical storms, and severe thunderstorms all pose a threat to the survival of the Southeastern Beach Mouse and the incubating sea turtle eggs along the coast. Climate change is projected to influence the occurrence of more severe thunderstorms and alter the patterns of hurricanes and tropical storms as both sea and land temperatures increase and fluctuate invariably. These major storms have been seen in the past to wipe out dunes through erosion by wind and waves exposing nests and mouse burrows. Additionally, storm surges can leave the nest to be inundated for prolonged periods by water and the burrows of the beach mouse washed away. Without proper adaptation to these storms, these species will face increased harmful impacts to their population size and procreation abilities.

4.3.5 Anthropogenic Development

With the Floridian population expected to increase to 26 million people by 2040, anthropogenic development along the coast will accelerate and overtake land with essential habitat corridors for the Southeastern Beach Mouse (University of Florida, 2015). The Loggerhead Sea Turtle will also find it harder to locate ideal nesting beach as dunes are replaced with seawalls and other barricades to protect investments made near the shores. If policy is not created to protect these lands from further development these and many other species will experience the loss of their habitat and draw closer to extinction.

5 DECISION MAKING PROCESSES

5.1 ADAPTATION TO SEA LEVEL RISE

Anthropogenic developmental activities pose the greatest threat to inhibiting the natural migration of some of these ecosystems landward in the face of sea-level rise. Maintaining and securing corridors and pathways is going to be the responsibility of several governmental and nongovernmental stakeholders that must be a part of the decision making process moving forward. These decision makers include the array of government agencies that include:

- U.S. Fish & Wildlife Conservation Commission;
- United States Department of Agriculture;
- Transportation Sector;
- Army Corps. of Engineers;
- Florida Local and State Government;
- Water Management;
- Non-Governmental Organizations (NGOs).

Besides these agencies and organizations the public must also be brought in to create proper adaptation strategies for these vulnerable ecosystems as private landowners must be on the same page as the government agencies that want to properly protect not only their own interests but the overall integrity of the Pelican Island National Wildlife Refuge ecosystems that exist within the Indian River Lagoon system. Developers and Architects must also be a part of the communication between these organizations as changes may also need to be made to the development of future projects on the coastal areas of Florida's eastern coast. NGOs will also be pivotal in putting pressure on the federal and state governments to participate in adaptation strategies in the future. Each of these stakeholders listed will have to communicate with one another and come to terms with the partitioning of certain responsibilities and recognition of relationships between hazards and vulnerabilities and their respective agency/organization that threatens the ecosystems we have described. Implementing foresight will be integral to adaptation strategies proving successful in the future. Collaboration and proper risk analysis must always precede action that seeks to safely mitigate and adapt to the changes we foresee happen while also constantly discerning what burgeoning hazards may develop as well.

5.2 ADAPTATION TO CLIMATE CHANGE

Stakeholders are individuals or groups who have the current and previous experience of coping with, and adapting to, climate variability and extremes, as well as those impacted by it (Lim et al., 2004). Stakeholders, at different levels and stages, are crucial to the success of an adaptation project due to their knowledge and expertise. The collective views of all stakeholders can build a comprehensive understanding of the issues, highlighting priority areas for action that take account of all stakeholders' perceptions. The stakeholders of south Florida include agricultural interests, environmental interests, recreational interests, residents, local tribes, and various local, state, and federal agencies (Dennis and Pardue, 2015).

Business and developers are a large stakeholder group due to the reliance on tourism and those that travel to Florida for the winter (snow birds). This includes entertainment businesses, restaurants, tourist accommodations, and retail trade. The perspective from business and development in South Florida is mainly short-term. They are concerned with attracting as many people as possible to the South Florida area and are not largely concerned with the long-term implications of factors due to climate change.

Florida state and local governments are another impactful group of stakeholders that includes officials, policy makers, and legislation. The perspective from these stakeholders can vary between short-term and long-term. Political representatives are expected to deal with a myriad of diverse issues of societal concern (Kiker et al., 2001). The issues are generally of immediate interest and competitive. That is, there are groups with diverse and sometimes conflicting agendas attempting to put pressure on the political representatives to have decisions go their way. Their time horizons are typically short; often it seems just until the next election. For issues extending over long periods, decades for ecosystem restoration, the political representatives desire justifications that are seen by the public as transcending politics.

However, there have been long-term goals achieved within the governmental stakeholders as well. Under interagency agreements a South Florida Ecosystem Restoration Task Force (Task Force) was created in 1993 (Kiker et al., 2001). This formal task force conducted its activities through the South Florida Ecosystem Working Group (consisting of representatives from 13 federal agencies, seven Florida agencies and commissions, two American Indian tribes, and 16 counties) and several less formal teams (the Science Coordinating Team). Further action was brought about by elements of the Federal Water Resources Development Acts of 1992 and 1996. The purpose of these long-term goals is to insure the welfare of the local ecosystems, and by doing so, ensuring the welfare of the local people. Federal agencies such as the Department of Homeland Security, Navy, and Army Corps of Engineers tend to take on a long-term perspective due to their necessity to protect and fortify specific areas within the United States.

The conservation and environmental agencies, as well as NGO's are all extremely important stakeholders in scientific studies and environmental protection; however, their perspectives vary as well. Agencies such as the United States Fish and Wildlife Service (FWS) and the National Park Service (NPS) are devoted to protecting ecosystems; however, due to their federal ties, they tend to have relatively short-term goals. Among the responsibilities of the FWS are enforcing federal wildlife laws, protecting endangered species, conserving and restoring wildlife habitat, and helping foreign governments with their international conservation efforts (U.S. Fish and Wildlife Service). The National Wildlife Refuge System Improvement Act of 1997 includes the nation's broadest statutory commitment to ecosystem protection: to "ensure that the biological integrity, diversity, and environmental health of the system are maintained."

The act also directs the FWS to expand the scope of conservation monitoring, assessment, and management beyond refuge boundaries to encompass surrounding landscapes. Although the FWS and NPS would naturally focus on long-term goals to best protect wildlife and their habitats, the federal government system often requires a shortened version.

The Florida Department of Environmental Protection, Fish and Wildlife Conservation Commission, and Nature Conservancy on the other hand, have a long-term perspective when approaching ecological issues. The Florida Fish and Wildlife Conservation Commission (FWC) is a Florida government agency that manages and regulates the state's fish and wildlife resources and enforces related laws (Florida Fish and Wildlife Conservation Commission). FWC is responsible for managing Florida's fish and wildlife resources for their long-term well-being and the benefit of people. The Florida Department of Environmental Protection (FDEP) is the Florida government agency charged with environmental protection (Florida Department of Environmental Protection). NGO’s such as the Nature Conservancy focus on volunteer work and scientific research. The scientists in the various disciplines hold considerable knowledge, and the scientific basis of restoration is considerable (Kiker et al. 2001). Scientists know it will take much experience to re-establish fundamental ecological functions. To accomplish the necessary learning, scientists need the support and resources the political representatives can provide, but they desire the support without undue political interference.

Privately owned land such as that of local residents and Native American reserves fall towards having a short-term perspective as well as economy-based stakeholders, such as fisheries and agriculture.

Between the political representatives and the scientists are the policy makers and managers. They are responsible for weaving together broad directives from the political realm with the unfolding knowledge from the scientists. The goal is sets of activities that not only can be communicated both up to the political representatives and down to the scientists, but also have potential for being accepted by both groups as reasonable given the restoration goals. The political representatives want to assure their constituents that broad societal goals are being met, and the scientists desire to have their scientific community accept the restoration activities based on their science. To implement viable adaptation plans, various short-term and long-term perspectives from numerous stakeholders, such as scientists, political representatives, and many more, must be assessed.

5.3 SPECIES SPECIFIC ADAPTATION

The main stakeholder for support of the adaptation plans for the Loggerheads and Southeastern Beach Mice is the US Fish and Wildlife Services (USFWS). Other stakeholders include local government, private landowners and land trusts, whom are significant decision makers involved, as many of the potential future habitats are owned by these stakeholders. USFWS reported in their *Summary Report of the 2012 AFWA State Adaptation Activity Survey* that the main drivers for the lack of progress of adaptation plans and strategies were the lack of political support, funding, lack of time, as well as lack of staff expertise. Opening these fields for potential donations and volunteer support can help mitigate a portion of the lacking areas. Florida state parks are stakeholders as they have partnered with USFWS in the past. Having access to not only national wildlife refuges but also to state parks would provide more options and locations for potential habitats. Audubon Florida is an example of a non-profit organization that is a potential stakeholder in seeking funds for new habitat maintenance. Audubon Florida’s 2016-2020 agenda includes climate change and coastal conservation, as well as implementing and influencing climate adaptation strategies in 300,000 Acres of coastal wetlands and marshes. Partnering with Audubon Florida provides a holistic approach, not only benefiting Audubon Florida's several bird species under protection but an entire ecosystem shared between these species.

The general public is also a stakeholder involved in decision making, if the general public is better educated about these two species and why they are important to the ecosystem they may feel a greater push to assist by volunteering or donating.

6 OPTIONS

6.1 ADAPTING TO SEA LEVEL RISE

It is important to remember that sea level rise varies greatly in any region or location when considering vertical land movement and ocean dynamics. Two questions should be considered when thinking about available options that coastal systems have: What keeps the systems adaptive, and what will help them adapt faster? A slower rate of sea level rise (.8 m by 2100) would allow the barrier islands to migrate inland, helping the system adapt to the influx of salinity. Higher projections, such as 1.8 m by 2100, where dune and barrier island migration would not occur, would lead to a loss in coastline protection.

One option is to slowly allow saltwater intrusion into the system to facilitate adaption overtime; but, as mentioned earlier, most ecosystems will shift into saltwater marshes. We have been unable to determine any corridors available for these ecosystems to utilize in migration, due to urban development along the coastline.

With current sea-level rise projections threatening these ecosystems, it is imperative to start predicting barrier island change (Zinnert et al., 2017). We anticipate that the barrier islands will transition into an inundation regime. This would destroy coastal dune ecosystems and weaken the protection dunes and barrier islands provide to the coastline. The local community in Vero Beach, Florida has begun to invest in the protection of their homes by building seawalls on their beach-front properties. Seawalls are an option, but are not recommended due to their negative impacts on habitats and wildlife. Therefore, we are recommending nature-based coastal defenses to combat sea-level rise.

6.2 ADAPTING TO CLIMATE CHANGE

Options:
1. Prescribed Burns
2. Continued Monitoring
3. Partnerships with Local Colleges
4. Ecosystem Engineering
5. Education Events
6. Sustainable Landscaping: Rehabilitation & Restoration
7. “Hands-off/Wilderness Approach”

Ecosystems in Florida face severe drought, wildfires, snap freezes, changes in weather patterns, and ecosystem degradation among a myriad of other serious crises with the changing climate. These issues all must be addressed and rectified in order for the state to continue operating successfully. This section presents possible solutions and options to help mitigate, and adapt to, several of these looming crises.

Recommendations on which of these options are the best for the ecosystems of Pelican Island and Merritt Island are discussed in Section 7.2.

Many options for both ecosystems in the Vero Beach area of Florida overlap due to the many similarities of the ecosystems. Prescribed burns and continued monitoring are two of these options. Likewise, a partnership with local colleges, further education for locals and tourists, as well as ecosystem engineering are options with benefits for both ecosystems. These options are all viable particularly when they are applied in an area-specific manner.

Merritt Island, for example, has plant life that could benefit from very carefully timed, closely monitored prescribed burns (Breininger & Smith, 1992). As this island also has a residential section, it would be imperative that these burns be very well controlled. These burns are preventative measures, and though extremely dangerous, can lessen the threat of wildfires during periods of extreme heat and drought. Similarly, sustainability landscaping, focusing on prevention of soil erosion, and lessening the impacts of fire could help the ecosystem survive the coming climate changes (Seabrook et al., 2011). If these methods fail, back burning is a possible method to fight wildfires as they occur, though the best possible scenario is prevention over literal firefighting. Developing a plan to help manage and ensure the continued survival of endangered plants and wildlife is also necessary, even if that plan requires the capturing and managed breeding of said species. Continued monitoring of species richness and evenness, plant health and location, water and soil quality and wildlife health is imperative to ensure the ecosystem continues functioning at its best.

Continual monitoring at Pelican Island in a similar fashion is also an option for ensuring the health of the ecosystem. The same metrics could be measured on land and at the oyster beds. Water salinity, acidity, and algae levels should also be monitored. Prescribed burns, and sustainability landscaping could be useful on Pelican Island much like on Merritt Island, and restoration pathways to help the trees and the migration of birds on the island is another option to help the ecosystem thrive. Importantly ecosystem engineering, both rehabilitation and restoration are possibilities for Pelican Island and its oyster beds (Lewis, 2005). A solid plan to help maintain the ecosystem or help it transition to its next step cyclically is another option for Pelican Island.

6.3 SPECIES SPECIFIC ADAPTATION OPTIONS

Options:
1. Allow natural migration to occur
2. Continue restoring/ managing beaches
3. Translocation
4. Continue creating habitat corridors
5. Improvements to temperature gradients
6. Captive breeding

Natural Migration of the Loggerheads and Beach Mice to future habitats that are less severely impacted by the current threats would be an ideal option. As we can see from the data provided by NOAA, projections for sea level rise indicated that by 2100, sea level may be 1.8 m higher than today. Therefore, sea-level rise related threats are approaching rapidly and the option for natural migration may not be attainable. Continuing restoration and beach management on the Southeast barrier islands of Florida and hot spots such as Archie Carr NWR in order to sustain them as much as possible is a short term option that may ultimately be ineffective with our knowledge of future projections. Translocation of Beach Mice as well as Loggerhead nests to a more suitable future habitat is another option that can be achieved with the assistance of local biologists. Finding future sites for the species would best be achieved with the use of models that simulate future impacts. Improving strategies to reduce the temperature of sand around incubating Loggerhead nests will better mitigate effects from climate change on the reproductive output of Loggerheads and their sex ratio (Jourdan & Fuentes, 2015). Corridors for Beach Mice along the coast to increase the natural migration of the species would also be beneficial. Beach Mice and other species may have physical, behavioral or physiological limitations in their abilities to migrate at an increased rate. Corridors give species the ability to do so to increase their chances of natural migration and survival (NRCS, 1999).

Captive breeding is another alternative to support a population that can be released back into the wild in a more suitable habitat. Captive breeding is not the preferred option as there have been documented physical and behavioral deficiency when reintroduced to the wild (Snyder et al.,1996).

7 RECOMMENDATIONS

Defending and increasing the resilience of the coastal ecosystems that show the most promise in longevity should be the highest priority for the stakeholders. Coastal dune ecosystems can be severely impacted by storms and hurricanes. Rising sea levels may cause dunes to erode if they are unstable or not restored after storms. Native dune plant species help stabilize the dunes, but are typically not available to the community. This causes the dunes to become more susceptible to erosion, and their instability will increase until they have eroded away (The Nature Conservancy, 2014). The U.S Fish & Wildlife Service should continue to extract invasive plant species from coastal dune ecosystems, and have native plant species readily available in nurseries for the people in the community. They can plant these species immediately after any storms or hurricanes, aiding in dune restoration. People will want to protect their properties from storms, eroding beaches, and sea-level rise, so we encourage promoting community-based volunteer programs to restore the dunes.

The U.S. Fish & Wildlife Service should continue to educate the community about the importance of dune ecosystems. Public awareness and understanding of the hazards seawalls pose to beach disappearance and migration (Figure 22) will be crucial in the implementation of sustainable policies and practices. We recommend hosting special events on Pelican Island and Merritt Island with interactive exhibits. This would be an effective way to engage the public and get them excited about conservation. Staging “what-if” scenarios and having special event attendees create plans to “save” the islands could be a truly innovative way to get people to care, become more knowledgeable and invested in the coastal ecosystems near them. Similarly, partnerships with local colleges to have students intern and do research is a possible way of managing potentially overwhelming amounts of data. Students could also help create plans for management of species on both islands and could even help organize the public events.

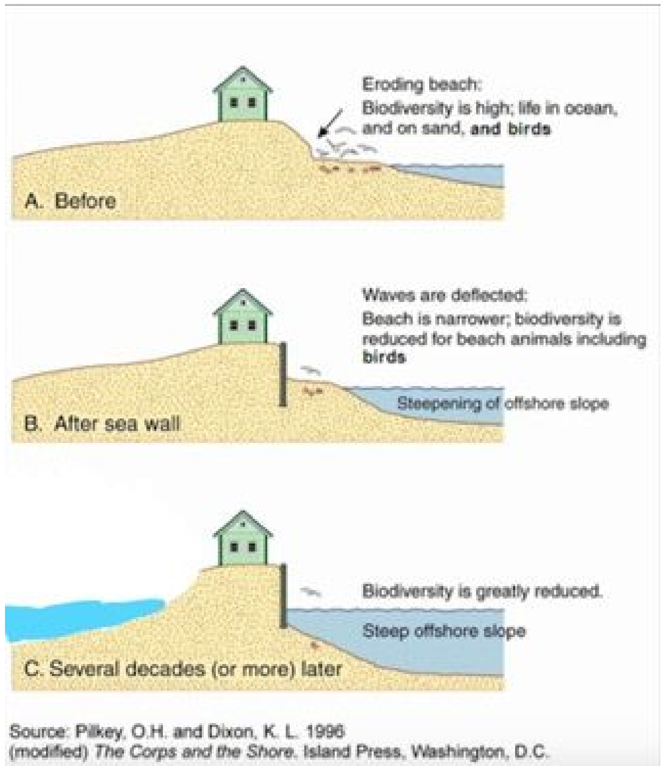

Figure 22: The negative effects of seawalls, and their uselessness as water rises from the lagoon side (backside) of the island. Modified from (Pilkey & Dixon, 1996).

Figure 23: An aerial view of Wabasso Beach, Florida. From Google Maps.

These images in Figure 23 show us that as sea levels rise, sea walls will eventually be breached as beaches migrate inward (Pilkey & Dixon, 1996); but water is rising mostly from the lagoon, flooding the area from the backside. This renders seawalls useless. If undeveloped beaches are protected and remain undeveloped, then it will be easier to manage and restore dunes. Seawalls would not be necessary, as dunes offer the same, natural protection. Beaches that are currently undeveloped should be protected and remain as they are, so coastal ecosystems can have access to pathways for species and ecosystem migration.

Another recommendation is the preservation of mangrove populations and habitats, through implementation of wave attenuation, and aiding in accretion of sediment on barrier islands. A nature-based coastal defense recommendation is a riprap crib.

Figure 24: Riprap crib at West Lake Park in Florida. From the Nature Conservancy (2014).

Figure 24 shows a riprap crib in the West Lake Park Mitigation and Restoration Project (The Nature Conservancy, 2014). A riprap crib reduces wave action and protects the shoreline, but still allows water exchange, and can also provide habitats for small fish and marine invertebrates. If water in the lagoon is rising from the back, then a riprap crib can be used to protect the mangroves from over-wash. This project is a short-term plan, as it can be costly and might not be effective in case of more rapid sea level rise. Management should also continue their oyster restoration to reduce wave action on the shores of Pelican Island. Implementing and restoring the oyster beds can greatly help improve the other ecosystems around both islands as well. Oyster beds help improve water quality and can be a much-needed boost to mangrove ecosystems (Coen et al., 2007). This is where we recommend positioning of the riprap crib to protect and preserve the mangroves on the west side of the island (Figure 25), where water levels are rising.

Figure 25: Recommendation of riprap crib placement for Pelican Island

Prescribed burns if not properly managed and controlled can be very dangerous to the surrounding wildlife. However, if managed properly, they can drastically reduce the chance of, or impact of wildfires (Breininger & Smith, 1992). Merritt Island, in particular, has a lot to lose from wildfires as it has a significant residential area. Carefully timed and closely monitored prescribed burns during cooler, wetter seasons removes much of the litter or fuel that helps increase the intensity and duration of a wildfire. These burns also provide a much-needed service to the ecosystem by allowing plants that need fire for reproduction to germinate. Another option to help these particular plants would be to attempt to breed them in captivity and then use sustainable landscaping techniques in order to plant them and reintroduce them to the ecosystems in the most effective manner.

Creating a plan to help maintain or restore species richness to an area, in order to help maintain the current ecosystem and restore healthy levels of biodiversity could be a viable option for these two island ecosystems. The two main questions one must consider are: “Is this sustainable? and “Who are we benefitting by keeping the ecosystem the way it is currently?” (Bullock et al., 2011). It is possible that allowing the ecosystem to transition to a new, different ecosystem may be the most sustainable choice. With the anticipated changes in climate, specifically in precipitation and temperature, that may be the only viable option (Landres, 2010). The general idea behind this hands-off approach would be to allow the area to return to “wildness”. This would mean that the “managers” of this area should in fact “refrain from taking actions that manipulate, control, or intervene with the ecological system (Landres, 2010).” This would allow the ecosystem to adapt to the changes in climate as they occur. This approach has the merits of being far less expensive to fund as it requires less active participation from people although this option would likely result in the loss of some species. This method operates under the assumption that those species would be replaced by others that are more able to thrive in the new environment. If in fact this hands-off approach is chosen, close monitoring of the area is strongly recommended.

Maintaining and managing original beaches of inhabitants of the two species, beach mice and sea turtles, as well as translocation would be preferred. 80% of Loggerhead sea turtles nest on the southeast coast of Florida, primarily Archie Carr NWR (Figure 26). By working to improve the existing habitats as well as the future habitats as an ecosystem as a whole, we can not only provide a safer and healthier ecosystem for the Loggerhead nests and beach mice, but also for other animals in the ecosystem. By doing so more organizations will become involved in the management of these habitats. To discern which sites will most likely see the most success in the future comprehensive modeling will be necessary. Multiple models must be assessed that reveal impacts of sea level rise, human development, population increase, infrastructure, temperature forecasts, extreme weather events, and Gulf stream shift. Along with the management of their habitat, creating regulations to provide a greater buffer zone between natural dunes and human developments such as seawalls would reduce the impacts of development on Beach Mouse and Loggerhead habitat.

We also urge that more research on improvements to temperature gradients for Loggerhead nests must be conducted to help mitigate the effects of climate change altering the sex ratio of Loggerheads. The study done for Mitigation and Adaptation Strategies for Global Change found that sprinkling on sea turtle nests at night as well as the use of artificial shade structures (Semi-transparent solar weave fabric) reduced the temperature of the sand by average 2.23 ± 0.66 °C and 1.43 ± 0.94 °C (Jourdan & Fuentes, 2015). Sprinkling, artificial shade and translocation of lighter sand are strategies for a short-term recommendation to regulate temperatures for Loggerhead nests.

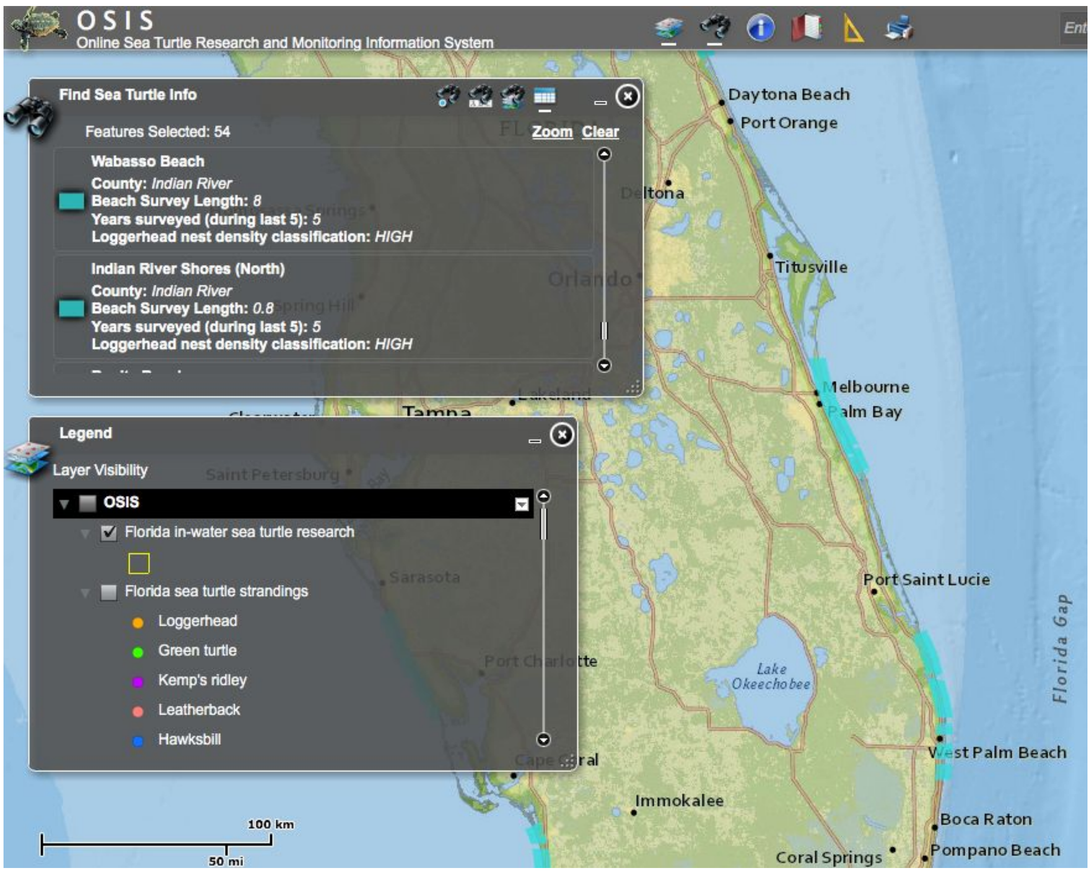

Figure 26: Range for Loggerhead nesting sites along the southeast coast of Florida (https://ocean.floridamarine.org/seaTurtle/OSIS/flexviewer/)

Translocation of a small fraction of Loggerhead nests as well as about 15 pairs of Beach Mice are another option. As we have seen in the more recent nesting seasons there have been record numbers of Loggerhead nests along Archie Carr National Wildlife Refuge as well as along the barrier islands of the southeast coast of Florida. Therefore, this would be an ideal time to translocate a number of nests to a new location, as we may be able to afford the risk of translocating these nests. (Bill Miller, 2017, personal communication). Translocating the nests back into a beach provides a more natural approach in allowing Loggerheads to hatch in a natural habitat rather than in captivity. As Loggerheads exhibit site fidelity in preferred areas, they will return to this specific site after completing their seasonal migrations (Mendonca et al., 1995).

Translocation is generally inexpensive as the species are just taken from one location and transported to another (Sandra Sneckenberger, 2017, personal communication). For the beach mice, as little as 15 pairs of adult beach mice would be ideal to start growing a population at a new site. Slowly building a population of Loggerheads that will return to the new site in the future after reaching sexual maturity (17-35 years) could potentially create a new hot spot for this species. We also recommend the management of the future sites for Loggerheads and Beach Mice so that we can assess the success of the adaptation plan.

Recommended sites for future beach mouse translocation are shown in Figure 28. Recent trappings/sightings of Beach Mice from potential donor sites have been found in areas of Smyrna Dunes Park, Canaveral national Seashore and Merritt Island National Wildlife Refuge (Sandra Sneckenberger, 2017, personal communication). A suggested recipient site with 1091 acres of habitat is Hobe Sound National Wildlife Refuge (USFWS, 2016). Hobe Sound would still have a large area for habitat for a projected sea level rise of 1.8 m by 2100 (Figure 27).

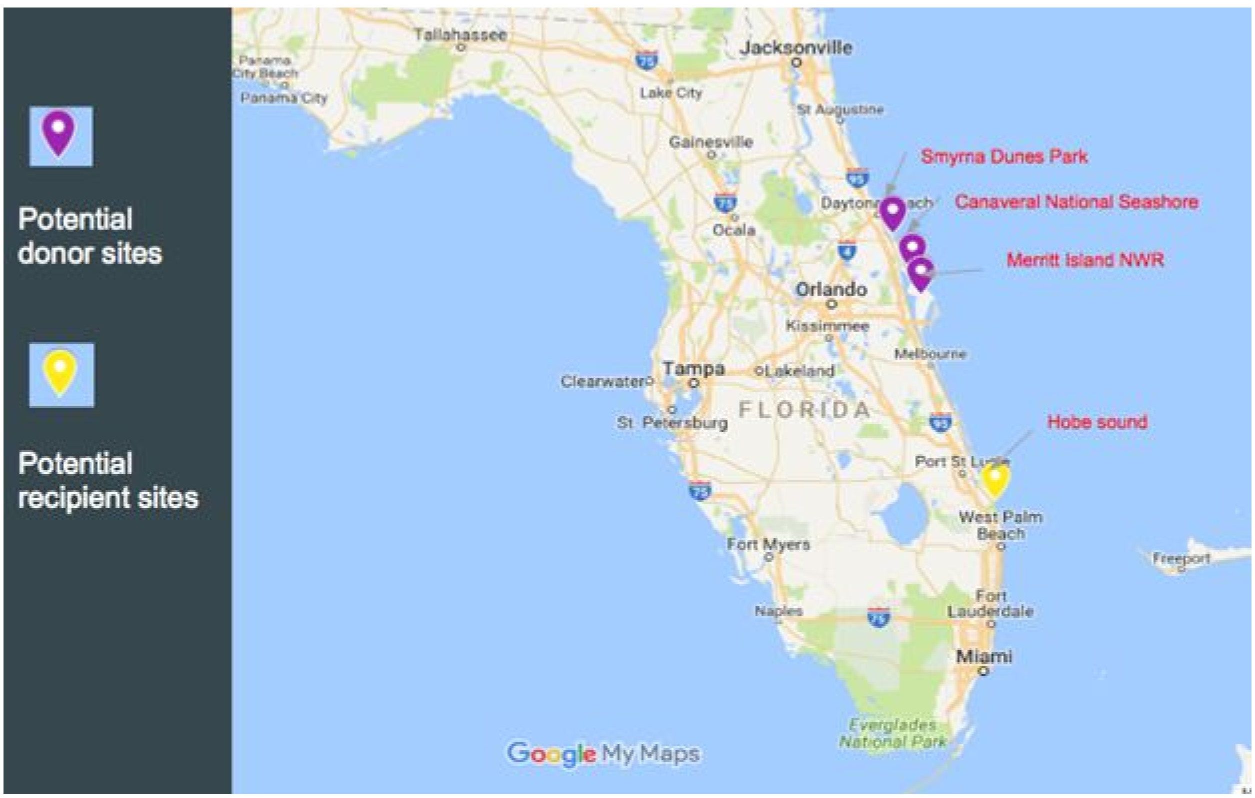

Figure 27: Donor and recipient sites for translocation of Southeastern Beach Mouse. (Image created using Google Maps)

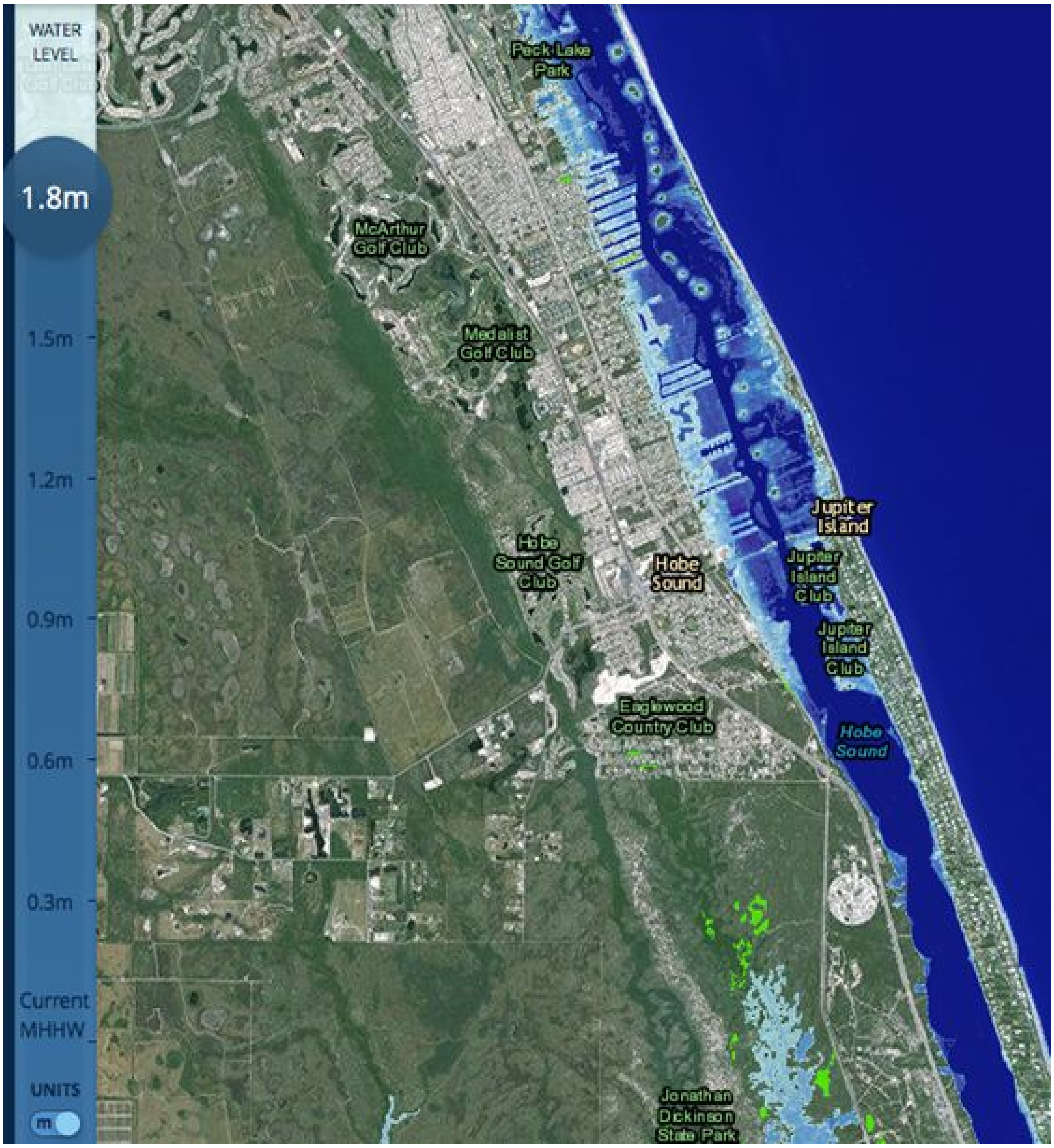

Figure 28: Sea level rise projections for Hobe Sound National Wildlife Refuge. 2100 (https://coast.noaa.gov).

Current efforts to protect ecosystems from sea-level rise may be futile if the highest level projections are not considered, and the U.S. Fish & Wildlife Service should begin to prepare for worst case scenarios. We recommend continuous reassessment of Pelican Island National Wildlife Refuge and other coastal ecosystems of interest on the order of every 4-5 years in order to gauge the effectiveness of adaptation strategies and discern emerging hazards not previously considered and adapt plans accordingly.

7.1 RECOMMENDATIONS SUMMARY

The recommendations presented for the hazards and vulnerabilities from sea level rise focus solely on nature-based coastal defenses so that habitats and biodiversity are not negatively affected. The two nature-based coastal defenses that were recommended are dunes restoration projects and a riprap crib to protect mangroves on Pelican Island. Dune restoration would hopefully decrease the need for seawalls. This would be a positive effect for species adaptation as one recommendation was to maintain and manage original beaches of the loggerhead sea turtle and the beach mouse. Overall, these nature-based coastal defenses would be beneficial to the beach ecosystem to protect the habitats and species from sea level rise.

Potential impacts on Florida from climate change require multiple recommendations. An interactive and educational approach is recommended for both Pelican Island and Merritt Island. These recommendations would hopefully gain the attention of the general and local public in preserving these wildlife refuges. Other recommendations include prescribed burns, as well as a “hands off approach.” Though these recommendations were made taking into account the impacts of climate change, it is important to remember that ecosystem managers may have to choose to protect the current biodiversity or to support the most sustainable ecosystem.

REFERENCES

Aich, Sumanjit, McVoy, Christopher W., Dreschel, Thomas W., Santamaria, Fabiola. 2013. "Estimating soil subsidence and carbon loss in the Everglades Agricultural Area, Florida using geospatial techniques." *Agriculture, ecosystems & environment* 171: 124-133. Retrieved: 2017. www.sciencedirect.com/science/article/pii/S016788091300100X

Alicyn R. Gitlin, Christopher M. Sthultz, Matthew A. Bowker, Stacy Stumpf, Kristina L. Paxton, Karla Kennedy, Axhel Muñoz, Joseph K. Bailey, Thomas G. Whitham. 2006. Mortality Gradients within and among Dominant Plant Populations as Barometers of Ecosystem Change During Extreme Drought. Retrieved: 2017. http://onlinelibrary.wiley.com/doi/10.1111/j.1523-1739.2006.00424.x/full

An Update of the Effects of Climate Change on Florida's Ocean and Coastal Resources. (2010, December). *Climate Change and Sea-Level Rise in Florida*. (F. O. Council, Compiler) Tallahassee, Florida. Retrieved: May 2017. http://www.dep.state.fl.us/oceanscouncil/reports/Climate_Change_and_Sea_Level_Rise.pdf

Association of Fish and Wildlife Agencies. 2012. The State of State Fish and Wildlife Climate Adaptations, Summary Report of the 2012 AFWA State Adaptation Activity Survey. PDF. Retrieved: 2017. http://www.fishwildlife.org/files/AFWA2012-StateClimateAdaptationReport.pdf

Bird, Brittany L., Lyn C. Branch, and Mark E. Hostelter. 2016. "Beach Mice." EDIS New Publications RSS. Wildlife Ecology and Conservation, 16 Mar. 2016. Retrieved: 13 June 2017. http://edis.ifas.ufl.edu/uw173

Bolstad, Erika. 2016. "Seas Rising but Florida Keeps Building on the Coast." Scientific American. ClimateWire, 20 June 2016. Retrieved: 13 June 2017. https://www.scientificamerican.com/article/seas-rising-but-florida-keeps-building-on-the-coast/

Branch, Lyn C. , Mark E. Hostler, and Brittany L. Bird. 2016. "Beach Mice." EDIS New Publications RSS. Wildlife Ecology and Conservation, 16 Mar. 2016. Retrieved: 13 June 2017. http://edis.ifas.ufl.edu/uw173

Breininger, D.R. and Smith, R.B., 1992. “Relationships between fire and bird density in coastal scrub and slash pine flatwoods in Florida.” American Midland Naturalist, pp.233-240. Retrieved: June 2017. http://www.jstor.org/stable/2426529?seq=1#page_scan_tab_contents

Bullock, J.M., Aronson, J., Newton, A.C., Pywell, R.F. and Rey-Benayas, J.M., 2011. “Restoration of ecosystem services and biodiversity: conflicts and opportunities.”

Trends in Ecology & Evolution, *26*(10), pp.541-549. Retrieved: June 2017. http://www.sciencedirect.com/science/article/pii/S0169534711001777

Caitlyn Kennedy, Rebecca Lindsey, 2014. How is the polar vortex related to the Arctic Oscillation. Retrieved: 2017 https://www.climate.gov/news-features/event-tracker/how-polar-vortex-related-arctic-oscillation

Coen, L.D., Brumbaugh, R.D., Bushek, D., Grizzle, R., Luckenbach, M.W., Posey, M.H., Powers, S.P. and Tolley, S.G., 2007. "Ecosystem services related to oyster restoration." Marine Ecology Progress Series, 341, pp.303-307. Retrieved: June 2017. http://www.intres.com/abstracts/meps/v341/p303-307

Commission FF and WC. 2017. Florida Fish and Wildlife Conservation Commission. Retrieved: 29 May 2017. http://myfwc.com/

Cox PM, Betts RA, Jones CD, Spall SA, Totterdell IJ. 2000. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature 408:184–187. http://www.nature.com/doifinder/10.1038/35041539

Dennis M, Pardue J. 2015. Florida Fish and Wildlife Conservation Commission Wildlife Updates and Stakeholder Meetings. Retrieved": 29 May 2017. http://www.bda-inc.com/news/062015_memo.pdf

Eric Carey Executive Director, Bahamas National Trust. "Coasts · Audubon Strategic Plan, 2016-2020." *Audubon*, strategicplan.audubon.org/coasts#conservation. Retrieved: 13 June 2017. http://strategicplan.audubon.org/assets/SP16_Full_Web_Res.pdf

Evans, Rob L. November 2004. "Rising Sea Levels and Moving Shorelines: New Tools and Techniques Show Promise For Better Predictions and Decisions About Coastline Change. *Oceanus Magazine*. Woods Whole Oceanographic Institution, Retrieved: May 2017. http://www.whoi.edu/oceanus/feature/rising-sea-levels-and-moving-shorelines

Feely RA, Sabine CL, Fabry VJ. 2006. Carbon Dioxide and Our Ocean Legacy. https://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

Fisher, Leah R., Matthew H. Godfrey, and David W. Owens. 2014. "Incubation Temperature Effects on Hatchling Performance in the Loggerhead Sea Turtle (Caretta Caretta)." Ed. Geir Ottersen. PLoS ONE 9.12 (2014): e114880. PMC. Retrieved: 13 June 2017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4269397/

Florida Department of Environmental Protection. "Integrated Water Quality Assessment for Florida:2014 Sections 303(d), 305(b), and 314 Report and Listing Update."

Tallahassee, FL April 2014.
http://www.dep.state.fl.us/water/docs/2014_integrated_report.pdf

Florida Oceans and Coastal Council. "Climate Change and Sea-Level Rise in Florida an Update of the Effects of Climate Change on Florida's Ocean & Coastal Resources." December 2010.
http://www.dep.state.fl.us/oceanscouncil/reports/Climate_Change_and_Sea_Level_Rise.pdf

Fuentes, M.M.P.B., Limpus, C.J. and Hamann, M. 2011. Vulnerability of sea turtle nesting grounds to climate change. Global Change Biology, 17: 140–153. doi:10.1111/j.1365-2486.2010.02192.x. Retrieve3d: 2017
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02192.x/abstract

Gitlin AR, Sthultz CM, Bowker MA, Stumpf S, Paxton KL, Kennedy K, Muñoz A, Bailey JK, Whitham TG. 2006. Mortality Gradients within and among Dominant Plant Populations as Barometers of Ecosystem Change During Extreme Drought. Conserv. Biol. 20:1477–1486.
http://doi.wiley.com/10.1111/j.1523-1739.2006.00424.x

Grenfell, M.C., Ellery, W.N., Garden, S.E., Dini, J. and Van der Valk, A.G., 2007. "The language of intervention: A review of concepts and terminology in wetland ecosystem repair." Water SA, 33(1), pp.43-50. Retrieved: June 2017.
https://journals.co.za/content/waters/33/1/EJC116403

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S. and Schmid, B., 2005. "Effects of biodiversity on ecosystem functioning: a consensus of current knowledge." Ecological monographs, *75*(1), pp.3-35. Retrieved: June 2017.
http://onlinelibrary.wiley.com/doi/10.1890/04-0922/full

Irizarry-Ortiz MM, Obeysekera J, Park J, Trimble P, Barnes J, Park-Said W, Gadzinski E. 2013. Historical trends in florida temperature and precipitation. Hydrological Processes. 27(16):2225-2246. Retrieved: 2017.
http://onlinelibrary.wiley.com/doi/10.1002/hyp.8259/full

Jennings D. 1999. South Florida multi- species recovery plan. Endangered Species Update. 16(2):SS22. Retrieved: 2017.
http://search.proquest.com/openview/724315784d902ae8729aa8ca65acc2b8/1?pq-origsite=gscholar&cbl=18750&diss=y

Jourdan, J. and Fuentes, M.M.P.B., 2015. "Effectiveness of strategies at reducing sand temperature to mitigate potential impacts from changes in environmental temperature on sea turtle reproductive output." Mitigation and Adaptation Strategies for Global Change, 20(1), pp.121-133. Retrieved: June 2017.
https://link.springer.com/article/10.1007/s11027-013-9482-y

Kennedy, Caitlyn, Rebecca Lindsey, 2014. How is the polar vortex related to the Arctic Oscillation. https://www.climate.gov/news-features/event-tracker/how-polar-vortex-related-arctic-oscillation

Kiker CF, Milon JW, Hodges AW. 2001. South Florida: The Reality of Change and The Prospects for Sustainability: Adaptive Learning for Science-Based Policy: The Everglades Restoration. Ecol. Econ. 37:403–416. Retrieved: 13 June 2017. http://linkinghub.elsevier.com/retrieve/pii/S0921800901001811

Landres, P., 2010. “Let it be: A hands-off approach to preserving wildness in protected areas [chapter 6].” Retrieved: June 2017. https://www.treesearch.fs.fed.us/pubs/37145

Larson, J. S. 2010. *Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Pelican Island NWR.* U.S. Fish and Wildlife Service National Wildlife Refuge System, Division of Natural Resources and Conservation Planning. Warren: Warren Pinnacle Consulting, Inc.. Retrieved: May 2017. http://warrenpinnacle.com/prof/SLAMM/USFWS/SLAMM_Presquile.pdf

Lewis, R.R., 2005. “Ecological engineering for successful management and restoration of mangrove forests.” Ecological engineering, 24(4), pp.403-418. Retrieved: June 2017. http://www.sciencedirect.com/science/article/pii/S092585740500042X

Lim B, Spanger-Siegfried E, Burton I, Malone EL, Huq S. 2004. Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures. Cambridge, United Kingdom: Cambridge University Press. Retrieved: 13 June 2017. http://www.preventionweb.net/files/7995_APF.pdf

Lohmann, K. J., N. F. Putman, and C. M. Lohmann. 2012. "The magnetic map of hatchling loggerhead sea turtles." Current opinion in neurobiology. U.S. National Library of Medicine, Apr. 2012. Web. Retrieved: 13 June 2017. https://www.ncbi.nlm.nih.gov/pubmed/22137566

Lopez J.. 2015. Sea-Level Rise and Species Survival along the Florida Coast. Climate Change Impacts on Ocean and Coastal Law. 2015 Oct 28:557–574. Retrieved: 2017

Marcovaldi, M.Â., Lopez, G.G., Soares, L.S., Lima, E.H., Thomé, J.C. and Almeida, A.P., 2010. “Satellite-tracking of female loggerhead turtles highlights fidelity behavior in northeastern Brazil.” Endangered Species Research, 12(3), pp.263-272. Retrieved: June 2017. http://www.int-res.com/articles/esr2010/12/n012p263.pdf

McPherson B, Hendrix G, Klein H, Tyus H. 1976. The Environment of South Florida, A Summary Report. Retrieved: 29 May 2017. https://pubs.usgs.gov/pp/1011/report.pdf

Mendonça, M.T. and Ehrhart, L.M., 1982. “Activity, population size and structure of immature

Chelonia mydas and Caretta caretta in Mosquito Lagoon, Florida.” Copeia, pp.161-167. Retrieved: June 2017.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014927.pdf

Miller, Deborah L., Brittany Bird, Lyn C. Branch, 2004. “Effects of Coastal Lighting on Foraging Behavior of Beach Mice” Department of Wildlife Ecology and Conservation, Newins-Ziegler. Conservation Biology. Volume 18, No. 5, October 2004. Retrieved: 2017
https://www.um.es/eubacteria/CL_RATONES.pdf

Morton, R. A. (n.d.). 2003. An Overview of Coastal Land Loss: With Emphasis on the Southeastern United States. St. Petersburg, Florida: Center for Coastal and Watershed Studies. Retrieved May 2017.
https://pubs.usgs.gov/of/2003/of03-337/landloss.pdf

Moses C, Anderson W, Saunders C, Sklar F. 2013. Regional climate gradients in precipitation and temperature in response to climate teleconnections in the greater everglades ecosystem of south florida. Journal of Paleolimnology. 49(1):5-14. Retrieved: 2017.
https://link.springer.com/article/10.1007/s10933-012-9635-0

National Oceanic and Atmospheric Administration. “Global and Regional Sea Level Rise Scenarios for the United States. January, 2017.” (NOAA Technical Report NOW CO-OPS 083). Silver Spring, Maryland: National Oceanic and Atmospheric Administration, U.S. Department of Commerce, National Ocean Service, Center for Operational Oceanographic Products and Services. Retrieved June 2017.
https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

National Wildlife Federation 2017."Loggerhead Sea Turtle." National Wildlife Federation. N.p., n.d. Retrieved: 13 June 2017.
https://www.nwf.org/Wildlife/Wildlife-Library/Amphibians-Reptiles-and-Fish/Sea-Turtles/Loggerhead-Sea-Turtle.aspx

Natural Resources Conservation Services. “Corridor Benefits” chapter 4. Nrcs.usda.gov Web. Retrieved: 13 June 2017.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_014927.pdf

NCA, 2014. *Climate Change Impacts in the United State: The Third National Climate Assessment*. U.S. Global Change Research Program. Washington, D.C. Retrieved: 2017.
http://admin.globalchange.gov/sites/globalchange/files/Ch_0a_FrontMatter_ThirdNCA_GovtReviewDraft_Nov_22_2013_clean.pdf

Park J, Obeysekera J, Irizarry M, Barnes J, Trimble P, Park-Said W. 2011. Storm surge projections and implications for water management in south florida. Climatic Change. 107(1):109-128. Retrieved: 2017.

https://link.springer.com/article/10.1007%2Fs10584-011-0079-8?LI=true

Parris, A., Peter Bromirski, Virginia Burkett, Dan Cayan, John Hall, Radley Horton, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. (NOAA Technical Report OAR CPO-1). Silver Spring, Maryland: NOAA. Retrieved: June 2017. http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf

Pelican Island National Wildlife Refuge. 2016. Retrieved May 2017. https://www.fws.gov/refuge/Pelican_Island/

Peter M. Cox, Richard A. Betts, Chris D. Jones, Steven A. Spall & Ian J. Totterdell, 2000, Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Retrieved: 2017. http://www.nature.com.proxy.lib.odu.edu/nature/journal/v408/n6809/full/408184a0.html

Plotkin, P.T., 1995. “National Marine Fisheries Service and US Fish and Wildlife Service status reviews for sea turtles listed under the Endangered Species Act of 1973.” National Marine Fisheries Service, Silver Spring, Maryland. Retrieved: June 2017.

Protection FD of E. 2012. Florida Department of Environmental Protection. Retrieved: 29 May 2017. http://www.dep.state.fl.us/mainpage/default.htm

Richard A. Feely, Christopher L. Sabine, and Victoria J. Fabry, 2006, Carbon Dioxide and Our Ocean Legacy. Retrieved: 2017. https://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

Sallenger, Asbury H. Jr. 2012. “Storm Impact Scale for Barrier Islands.” *Journal of Coastal Research*, vol. 16, no. 3, 2000, pp. 890–895. *JSTOR*. Retrieved: 2017. www.jstor.org/stable/4300099

Sea Level Rise Viewer. 2017. NOAA. Retrieved: June 2017. https://coast.noaa.gov/slr/#/layer/slr

Sea Turtle Conservancy. 2017. "Information About Sea Turtles: Threats to Sea Turtles” Sea Turtle Conservancy. N.p., n.d. Retrieved: 13 June 2017. https://conserveturtles.org/information-sea-turtles-threats-sea-turtles/

Seabrook, L., Mcalpine, C.A. and Bowen, M.E., 2011. “Restore, repair or reinvent: Options for sustainable landscapes in a changing climate.” Landscape and Urban Planning, 100(4), pp.407-410. Retrieved: June 2017. http://www.sciencedirect.com/science/article/pii/S0169204611000739

SEE Turtles. 2009. "Global Warming & Sea Turtles." SEE Turtles Organization. N.p., n.d. Retrieved: 13 June 2017.

http://www.seeturtles.org/global-warming/

Service USF and W. U.S. Fish and Wildlife Service. Retrieved: 29 May 2017. https://www.fws.gov/

SLAMM: Sea Level Affecting Marshes Model. September 2016. (Warren Pinnacle Consulting, Inc.) Retrieved: May 2017. http://www.warrenpinnacle.com/prof/SLAMM/SLAMM_Model_Overview.html

Sneed, A. June 2017. *How is Worldwide Sea Level Rise Driven by Melting Arctic Ice.* Retrieved: June 2017. https://www.scientificamerican.com/article/how-is-worldwide-sea-level-rise-driven-by-melting-arctic-ice/#

Snyder, N.F., Derrickson, S.R., Beissinger, S.R., Wiley, J.W., Smith, T.B., Toone, W.D. and Miller, B., 1996. "Limitations of captive breeding in endangered species recovery." Conservation Biology, 10(2), pp.338-348. Retrieved: June 2017. http://onlinelibrary.wiley.com/doi/10.1046/j.1523-1739.1996.10020338.x/full

State of Florida, Department of Environmental Protection. 2012. "Florida Geological Survey- Coastal Research Projects". Retrieved: June 2017. http://www.dep.state.fl.us/geology/programs/coastal/coastal.htm

Sweet, William V., Kopp, Robert E., Weaver, Christopher P., Obeysekera, Jayantha., Horton, Radley M., Thieler, E. Robert, and Zervas, Chris. 2017. *Global and Regional Sea Level Rise Scenarios for the United States*. Silver Spring: National Oceanic and Atmospheric Administration, Retrieved: 2017. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Taleb, N. N., 2010. The Black Swan: Second Edition: The Impact of the Highly Improbable Fragility. Random House Publishing Group. Retrieved: 2017. Print.

The Nature Conservancy, 2014. Nature-Based Coastal Defenses in Southeast Florida. Big Pine Key, Florida. Retrieved: 2017. https://www.nature.org/media/florida/natural-defenses-in-southeast-florida.pdf

Trenberth K. 2005. Uncertainty in hurricanes and global warming. Science (Washington). 308(5729):1753-1754. Retrieved: 2017. http://science.sciencemag.org/content/308/5729/1753

U.S. Fish and Wildlife Service 2017. "Southeastern Beach mouse (Peromyscus polionotus niveiventris)." Species Profile for Southeastern Beach mouse (Peromyscus polionotus niveiventris). Environmental Conservation Online System, n.d. Web. Retrieved: 13 June 2017. https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A0C9#conservationPlans

U.S. Fish and Wildlife Service. N.p., n.d. Web. Retrieved: 29 May 2017. https://www.fws.gov/

U. S. Fish and Wildlife Service. 2006. *Merritt Island National Wildlife Refuge [Electronic Resource] Draft Comprehensive Conservation Plan and Environmental Assessment*. Atlanta, Ga.: Atlanta, Ga.: U.S. Fish and Wildlife Service, Southeast Region.

U. S. Fish and Wildlife. 2002. *Pelican Island National Wildlife Refuge*. Washington, D.C. : U. S. Fish & Wildlife Service.

University of Florida. April 2015. Projections of Florida Population by County, 2015-2040. Retrieved: 2017. http://edr.state.fl.us/Content/population-demographics/data/MediumProjections_2014.pdf

Witherington BE, Bjorndal KA. Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles Caretta caretta. Biological Conservation. 1991;55(2):139–149. Retrieved: 2017. http://www.sciencedirect.com/science/article/pii/000632079190053C

Zinnert, Julie C., Thompson, Joseph A., Young, Donald A. "Immediate effects of microclimate modification enhance native shrub encroachment." Ecosphere, 28 February 2017. http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1687/full