CLIMATE CHANGE, SEA LEVEL RISE, AND THE HUMAN IMPACTS ON THE AMERICAN CROCODILE IN THE EVERGLADES NATIONAL PARK

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Executive Summary: Austin Greenhill, Kayla Berger, Rachel Case

Encompassing over 607 thousand hectares of land, the Everglades National Park (ENP) protects an unparalleled landscape that provides important habitat for multiple endangered species, including the American Crocodile (*Crocodylus acutus*). Three anthropogenic threats are discussed as specific hazards that are impacting, and projecting to further impact, the biotic and abiotic factors associated with the Everglades National Park: climate change, sea level rise, and urban development. Specific variables in the system of the Everglades National Park are becoming increasingly vulnerable to these hazards: Florida Bay's ecosystem, mangroves, and the American Crocodile. By better understanding how these hazards are impacting the system of the Everglades National Park, the more successful mitigation plans and adaptation strategies will be for mangroves and the American Crocodile. To change the future trajectory of the Everglades, the mangroves, and the American Crocodile, participation from the US Environmental Protection Agency, US Fish and Wildlife Service, state parks, tourists, private landowners, local government representatives, South Florida Water Management District, Florida energy company, and the Florida Fish and Wildlife Conservation Commission is vital. Participation from these stakeholders could help restore freshwater delivery from Lake Okeechobee to Florida's southern tip, ensure this water remains clean enough to sustain biota, aid in migration efforts, and ensure the protection of Lake Okeechobee's surrounding undeveloped lands.

Climate Change

Austin Greenhill

The interactions of climate change, sea level rise, and human impacts were studied in high, intermediate, and low risk scenario models to determine the possible outcomes for the American Crocodile inhibiting the ENP. Focusing only on climate change, it was observed that climate change does have a direct impact on the American Crocodile. Moving forward in our research, we identified the hazards to, and vulnerabilities of, the American Crocodile, Florida Bay's ecosystem, and Florida Bay's mangrove habitats. Of climate change related hazards, CO2 absorption, temperature rise, as well as increased intensity of extreme weathering events were deemed the most important. Also, more than 500 invasive species were found to roam the crocodile's natural territory due to human introduction and climate related shifts. The hazards listed are of particular importance due to nesting habitat degradation, male to female birth ratios,

and competition of essential space and resources. When evaluating the vulnerabilities of the Everglades, Florida Bay's ecosystem, the American Crocodile, and mangroves habitats were also identified as being of importance. All of which are heading into compromised futures with respect to invasive species, 25-35% higher water levels for Florida compared to the global average, and increased salinity levels. Increasing temperatures coupled with drought and rising CO2 levels are leading to the depletion of mangroves at a rate of .7-2.1% a year. The American Crocodile faces the future struggle of rising temperature, which could affect the male to female ratio of crocodile hatchlings. As temperatures continues to steadily rise, the number of male births is likely to increase, while the number of female births is likely to decrease. Consequently, this temperature-based system of birth determination will lower reproductive chances as climate change continues to further impact the American Crocodile's population stock.

Sea Level Rise

Kayla Berger

As the Everglades National Park exceeds in to an estuarine ecosystem, sea level rise may bring substantial changes to the system due to increasing dry-land loss from submergence and erosion. Recent studies have found that sea level is expecting to rise between 1 to 2 m in Southern Florida by 2100, which threatens this area's low-lying coasts where plant communities are organized along mid-gradient in elevation. If sea level does rise to 2 m by 2100, it is projected that all of Florida Bay, the southern tip of the Everglades National Park, will be inundated by saltwater intrusion. This salt water intrusion means that wildlife living on the edge of their physiological tolerance to salinity are not expected to survive.

Mangroves serve as an important aspect to the Florida Bay ecosystem and is currently being threatened by sea level rise due to high water levels creating an entrapment of carbon in the peat soil which supports their roots. Too much entrapment of carbon will eventually cause the peat to collapse. Mangroves are also an important nursery site for the American Crocodile, so the depletion of these plants will also create vulnerabilities to the crocs. American Crocodiles are also vulnerable to the hazard of sea level rise due to juveniles having a low tolerance to high salinity levels. As urban development and climate change are altering the freshwater flow in to the Bay, there is not enough fresh water balancing out the salt water that is flowing in to the bay. As this continues to happen, sea level rise will increase salinity levels in the Bay, which will leave an unsuitable environment for the American Crocodile.

Because of everything that is currently known about sea level rise, the American Crocodile's intolerance to salinity changes, and a decrease of freshwater flow, the best viable option for the success of the American Crocodile population would be to migrate north. It has been found that salinity levels are lowest in northeast areas of the Bay such as Taylor Slough, Turkey Point, and Crocodile Lake National Wildlife Refuge. These areas have been found to be ideal nesting and nursery habitat due to abundance of mangroves and low salinity levels. Further mitigation and adaptation strategies should be created to aid the American Crocodile to migrate to these designated areas.

Urban Development
Rachel Case

This portion of research was designed to gain a better understanding of the ecological impacts occurring from anthropogenic alterations. The historic Everglades extended from Orlando to the Keys, but in 1906 efforts were put into place to begin draining this ecosystem for the promotion of agricultural lands and urban development. Freshwater management practices were also set in place altering the natural sheet flow of water from Lake Okeechobee to the Everglades. As a result, the Everglades as well as Florida Bay, are faced with a multitude of problems revolving around the depletion of freshwater delivery to these ecosystems. Currently, more than 45% of freshwater received by Florida Bay is based on direct rainfall, while very little is received from the Everglades. Many species inhibiting Florida Bay are heavily dependent on a certain environmental makeup for the production of stable populations. Today, physiological characteristics are being challenged by hypersaline conditions due to reduced runoff and freshwater delivery, while ecological requirements are being challenged by projected human population growth and urban development. It is thought that by 2060, Florida's human population could reach 36 million, about 15 million higher than it is today. This is of particular concern being that 2.8 million hectare of additional lands could be converted for anthropogenic benefits. Species of concern include Florida Bay's estuarine species, the American Crocodile, and Florida Bay's mangrove habitats. Species inhibiting Florida Bay are placed under salinity stress, while the American Crocodile is running out of suitable space for nesting. The mangroves are challenged with both. Moreover, future projections shed light on what appears to be a grim future in the face of growing human populations, urban development in areas directly surrounding Lake Okeechobee, which the U.S Census Bureau currently reports as Florida's least

densely populated areas, and any decisions that may further restrict freshwater delivery to the southern tip of Florida.

In summary, this paper presents three mitigation and adaptation options to help preserve and protect the American Crocodile population in the Everglades National Park, and furthermore, Florida Bay. These options include the continuation of clean freshwater restoration efforts, the protection of Lake Okeechobee's surrounding undeveloped lands, limiting public access to Joe Bay to promote the enhancement of stable populations for the American Crocodile, as well as studying the spatial nesting and temporal patterns of the American Crocodile's nesting habitat to help form a management plan that will aid in migration. It is this paper hope that these recommendations are taken into serious consideration.

1 Introduction

Alexa Zwicker, Lena Midgette, Chase Garrison

Established in 1947, the Everglades National Park protects more than 607 thousand hectares of the southern tip of Florida. A mix of freshwater and coastal prairie, mangroves, marshland, pine, cypress woods, and the islands around the bay makeup this federally protected wilderness (National Geographic, 2009). In South Florida, there is a unique opportunity to integrate endangered species recovery and conservation with ecosystem restoration and management (National Park Service, 2017). The Comprehensive Everglades Restoration Program (CERP) began in 2000 to restore pre-drainage flows and preserve the natural habitat and landscape of the Everglades National Park (Dessu et al., 2018). However, CERP did not consider the cost and impacts of sea-level rise when creating this restoration program. A report from the National Park Service (2015) states that visitors to the Everglades National Park spent $104,476,500 in 2014 and provided jobs to 1,552 for a total benefit of $155,544,700 to the local economy.

The American Crocodile (*Crocodylus acutus*) population was declared endangered in 1975 according to the IUCN red list (Mazzotti, 1997). However, due to decades of conservation efforts, the crocodile population has risen, particularly nesting females (National Park Service, 2017). Although the population size is on the rise, they are still listed as a vulnerable species with threats expecting to rise as salinity and temperature increases in the Everglades National

Park. With the influx of invasive species, incoming predators are causing issues with the crocodiles food chain and also placing a strain on overall space. Invasive plants are also causing issues in the overall ecosystem that crocodiles are inhabiting. Crocodiles are an important part of the ecosystem because they are an indicator species and apex predator.

Mangroves are trees and shrubs that grow in coastal areas in either saline or brackish waters. They serve as one of the first lines of defense for coastal areas, are a major nursery for fishes and other marine species, and provide habitats and nestings sites for American Crocodiles. Two thirds of the nesting sites of the American crocodile occur in the Everglades National Park along sandy shorelines (Mazzotti, 1989).

In 2007, the United States Fish and Wildlife Service (USFWS) declassified the American crocodile as an endangered species, stepping the status down to “threatened”. To fight these declines, Joe Bay and two other bays including Snag Bay and Madeira Bay were part of the sanctuaries closed to public entry for the protection of the American crocodile (National Park Service, 2017) because they were prime breeding grounds and housed the perfect conditions for the population to recuperate. Crocodile density increased in Joe Bay in future scenarios (Green, et al., 2013) because overall salinity was lower due to more freshwater flowing in from a nearby slough. This resulted in favorable growth and survival conditions and a proportion of crocodiles moving in from surrounding areas with less favorable conditions. Joe Bay had been without public access for more than 30 years with efforts to bring the American crocodile back from close extinction. In November of 2016, the Everglades National park reopened Joe Bay to the public for the first time since 1980 (National Parks Service, 2017). Since then, the species population in Joe Bay has improved significantly. This decision was included in the park’s 2015 General Management Plan stating that the reopening of Joe Bay would provide needed resource protection while also providing new wilderness experiences for people visiting the park.

Continuing research on the American crocodile will further support conservation efforts and restoration plans for the future of the Everglades National Park ecosystem (National Park Service, 2017). With sea level rising it is vital to protect the American crocodile nests in the Everglades National Park (Mazzotti, 2003). With the added escalations of water level, and increased rainfall from climate change, the availability of nesting sites are decreasing with added erosion. These nesting sites are projected to disappear due to sea level rise in the next 30-100 years (citation needed). Additional stressors from human development and the increasing human

population, coupled with the rising sea level, the American crocodile is facing additional factors that can force it to migrate to other areas.

Figure 1.1 Map of Southern Tip of the Everglades National Park.

Figure 1.2 Zoomed in image of our system of focus: Joe Bay, Everglades National Park.

2 Hazards Impacting Joe Bay

2.1 Climate Change

Alissa Ralston

2.1.1 Temperature

The Florida Bay ecosystem supports a number of economically important ecosystem services, including several recreational fisheries, which may be affected by changing salinity and temperature due to climate change (Kearney et al., 2015). In the last century, the state of Florida has had an increase in average temperature by 1.5ºC (EPA, 2016). Current projections indicate that the average temperature in Florida may rise 2 to 5ºC between now and the next century (NRDC, 2001). The projected climate change has the potential to reduce water supply and limit flood control operations for all water sectors (Obeysekera et al., 2010). There are two scenarios that with temperature increase, the amount of rainfall will either increase or decrease with the latter being the more likely to occur (Obeysekera et al., 2010). Since the second scenario is more likely to occur, the increased temperature will cause a rise in evapotranspiration and because there will be a decrease in the median water level (Obeysekera et al., 2010).

2.1.2 Carbon Dioxide

"About half of cumulative anthropogenic CO2 emissions between 1750 and 2010 have occured in the last 40 years" (IPCC, 2007). The ocean has absorbed approximately 26% of the anthropogenic carbon dioxide deposited into the atmosphere over the last two centuries (IPCC, 2007). Daily, the ocean absorbs roughly 22 million tons of carbon dioxide, which has caused the ocean to become 30% more acidic in the last two centuries (IPCC, 2007). The pH of the ocean has dropped from 8.2 to 8.1 since the early 1900's, and is expected to continue to drop another 0.3-0.4 by 2100 (Bennett, 2018). Such a drastic change in pH doesn't give the fish enough time to adapt to their changing environment (Bennett, 2018). A real issue with scientists is that they don't know how different the ocean will look because of the effects ocean acidification will have on it in the future (Bennett, 2018).

2.1.3 Extreme weather

Droughts: The average rainfall is expected to change by as much as 10% within the next century (Obeysekera et al., 2010). An increase in evapotranspiration and a decrease in accumulated water from rainfall, will result in an altered water depth, decreasing between 5 and 114 cm (Nungesser, 2015). This will also pose a threat to frequently inundated areas in the Everglades, where the duration of being inundated will be greatly decreased, anywhere from 5% to 45% (Nungesser, 2015). While flooding and high water events are more likely to occur more often and provide short term relief, precipitation is still expected to make a significant decrease (Nungesser, 2015). This means that droughts are expected to become more harsh and longer in the coming years (Nungesser, 2015). Droughts and climate change will have a negative impact on any restoration effort for Southern Florida, especially with a decrease in water supply for humans (Nungesser, 2015).

Hurricanes: Hurricane intensity has been documented to be getting stronger, especially within the last 5 years (Rahmstorf, 2018). The most significant increase in intensity (by 99%) has occurred in the North Atlantic ocean, this could directly affect the Florida Keys (Rahmstorf, 2018). Wind speed also has increased, storms with wind speeds of up to 200 km/h will double while storms with wind speeds of up to 250 km/h will triple (Rahmstorf, 2018). The time between storms strong enough to cause storm surges, for example in New York, are expected to go from every 25 years to every 5 years in the next thirty years (Rahmstorf, 2018). Not only will climate change strengthen the storm, it will also expand the area where hurricanes occur, allowing the storms to expand poleward (Rahmstorf, 2018).

2.2 Sea Level Rise

Kayla Berger

Coastal ecosystems are the foundation for the quality of life and economies of many people across the globe, and sea level rise may substantially change these ecosystems by increasing dry-land loss due to submergence and erosion (Geselbracht et al., 2015). According to tide gauge records, global sea level rose at a rate of 1.8 mm/yr in the twentieth century, with most of the rise being due to thermal expansion and melting of glaciers (Zhang et al., 2011). The Intergovernmental Panel on Climate Change (IPCC, 2007) projected that global sea level would rise up to 0.6m by 2100. However, recent studies have found that IPCC (2007) may have greatly

underestimated the rate of sea level rise (SLR) due to the continued acceleration of the Antarctic and Greenland ice sheets (Zhang et al., 2011). Because of this, Vermeer and Rahmstorf (2009) created an updated equation to get a more accurate representation of SLR rate. This extended method derived an updated SLR projection of 0.7-1.9m of SLR by 2100 (Vermeer and Rahmstorf, 2009). As sea level is expecting to rise 1 to 2 m in southern Florida by 2100 according to Allison et al (2009), and because of Florida's low elevation, the impact of sea level rise is predicted to be 25-30% greater in Florida Bay than the global average, which threatens South Florida's low-lying coasts where plant communities are organized along mid-gradient in elevation (Saha et al., 2011).

According to Park et al. (2016), sea level is projected to rise between 0.067 m and 0.099 m in Florida Bay by 2025 based on a high-low scenario. These high to low scenarios are based on whether carbon emissions continue to rise and ice caps melt at a continuous rate, or if emissions and rates begin to plateau. This increase is not likely to change the topography or coastal fringe of the Bay. However, these same projections find a 0.2 m to 0.4 m increase in sea level by 2050, indicating that Taylor Slough (north east section of Florida Bay) will become significantly impacted by encroaching sea in both scenarios. By 2100, it is projected that nearly all of Florida Bay will be inundated by saltwater intrusion (Park et al., 2016).

2.3 Invasive Species

Lena Midgette, Austin Greenhill, Fallon Woolford

Exotic animals, plants, and invasive fish species, displace natives and threaten to disrupt ecosystem balance. These species are able to outcompete native flora and fauna for food and space due to lack of population controls such as predators and disease. These invasive species affect native ecosystems via alteration of habitat structure, competition, reduction of native predator populations, and alteration of trophic structure. Invasive predators can reduce or extirpate native prey populations (Dorcas, 2012).

2.4 Land Use Change

Alexa Zwicker

Population growth and urban development are also a hazard to the American Crocodile and the Everglades National Park. Currently roughly 330,000 people are moving into Florida

each year. There are 9.4 million housing units and 7.3f million households, with 20,984,400 people living in Florida as of 2017 (United States Census Bureau, 2017). Housing developments have invaded the wetlands and cover most of the southern part of the state so much so that half of the Everglades have been swallowed by development and much of the rest, the size Delaware, is not getting proper water flow (Negative Population Growth, 2018). Hendry County, which is in the middle of the Everglades, had a population of 6,051 in 1950, but by 1999, it had surpassed 29,000 (Negative Population Growth, 2018). It is projected that Florida's population will reach 25 million in 2030, and 32 million in 2050. Florida is also the third most immigrant receiving state (domestic and Foreign) and ranks fourth in illegal immigration. The U.S. Census Bureau projects that Florida will gain 1.9 million additional immigrants by 2025 further adding to the current population projected (Negative Population Growth, 2018).

Countries build levees as a means to control water level threats (i.e., flooding) in agriculture and residential areas. Governments have built levees as a way to control the direction of water flow (Encyclopedia of environment and Society, 2018). The water management system in southern Florida, which is made up of 4,507 km of levees, canals, and berms and 1,200 pumping structures, is one of the largest in the world and takes $240 million a year to maintain. These systems have displaced historic water flow to the southern tip of Florida therefore depriving Everglades National Park with the water each ecosystem needs. In 2014, the South Florida Water District budgeted more the $94 million for flood control and maintenance and then another $50 million for infrastructure improvements. The South Florida Water District is putting forth improvement efforts on the east coast protective levee which stretches 105 miles along the western perimeter of the most populated area of South Florida. The systems of levees and canals provide water to more than 7.0 million residents and businesses in southern florida (South Florida Water Management District, 2013). Although, these levees in southern Florida have displaced slough vegetation which has now been replaced with seagrass that in turn offers fewer refugees and forging areas for native wildlife. Canals and levees serve as pathways for non native species to enter and stay in the everglades, which threatens the habitat of not only the American Crocodile but other native species as well (IFAS, 2011).

Pollution in terms of eutrophication also threatens the Everglades and surrounding systems. Phosphates fertilize the growth of vegetation in water, and lead to accelerated eutrophication and the destruction to a body of water with excessive vegetation, particularly

algae makes bodies of water uninhabitable by valuable sport and commercial fisheries (Hearing of Congressional Subcommittee, 1969). The main sources of phosphate in aquatic environment is through household sewage water containing detergents and cleaning supplies, agricultural runoff containing fertilizers, as well as, industrial effluents from fertilizer, detergent and soap industries. The consumption of synthetic detergents is increasing year-by-year due to increasing urbanization and most of these products contain phosphate as a 'builder', which increases phosphate loading rates in water bodies (Kundu et al. 2015).

3 Vulnerabilities in Joe Bay in Response to Hazards

3.1 Florida Bay Ecosystem

3.1.1 Climate Change

Alissa Ralston

Expected to affect fish populations, either they will go extinct or there will be an increased rate of migration (Impacts on Florida's Fish and Wildlife, 2018). While ecosystems have the ability to adapt to gradual change, these ecosystems are being overwhelmed by dramatic increase in climate change and sea level rise (Impacts on Florida's Fish and Wildlife, 2018). This will also lead to some species even being able to adapt to their changing conditions (Impacts on Florida's Fish and Wildlife, 2018). One huge issue migrating wildlife face is the lack of corridors from Florida Bay, whether it's a fish, a bird, or even a crocodile they will have more issues finding safe places to live because of urban development (Impacts on Florida's Fish and Wildlife, 2018). An increase in ocean temperature will also cause things like a loss of adequate nurseries for adolescent fish and crocodiles (Impacts on Florida's Fish and Wildlife, 2018). This can also lead to nest failures and a change in the sex ratios of crocodiles and turtles(Impacts on Florida's Fish and Wildlife, 2018). Due to wildlife migrating because of climate change, this will also lead to an increase in nonnative and sometimes even invasive species in Florida Bay, this can pose a problem for the wildlife that stay in the area (Impacts on Florida's Fish and Wildlife, 2018).

3.1.2 Sea Level Rise

Kayla Berger

Small changes in local sea level can lead to significant changes in biological productivity, and disturbances in tidal marshes (Plag and Jules-Plag, 2013). Changes in these variables pose extreme challenges to the ecosystems, especially if these changes take place rapidly. Changes in local sea level is dependent on both changes in sea surface height and changes in land surface height. Local sea level rise is likely to increase the destructive force of coastal storms, leading to increased local erosion and an acceleration of ecosystem losses. As a consequence to increased erosion, the total shoreline retreat could be much larger than suggested by present-day topography (Plag and Jules-Plag, 2013). This will cause the Florida Bay to be extremely vulnerable to habitat and ecosystem service loss due to inundation. Since Southern Florida is one of the most vulnerable areas due to its low elevation and minimum relief, the hazard of sea level rise means that wildlife living on the edge of their physiological tolerance to salinity are not expected to survive (Pearlstine et al., 2010).

3.1.3 Human Impacts

Rachel Case

Florida bay is a shallow estuary that is made up of basins separated by mudbanks and lies at the southern tip of the Everglades National Park. This estuary is highly dependent on freshwater to maintain proper salinity levels suitable for sustaining a wide variety of ecological communities such as seagrass, mangroves, and freshwater marshes. Historically, fresh water was delivered to Florida Bay by the Everglades through natural sheet flow from Lake Okeechobee as well as direct rainfall. In more recent years, to accommodate rapid population growth, water management practices, such as the implementation of levees and canals, has severely altered the amount of freshwater entering Florida Bay's ecosystem (see Section 2.4).

Shallow mudbanks, restricted circulation, and the hydraulic connectivity of Florida Bay cause this ecosystem to be highly vulnerable to freshwater management (Kelble et al., 2007, Parker et al., 2016). Some basins in Florida Bay experience a greater degree of exchange, like marine basins in the southern and western bay, while coastal basins along the peninsula are far more restricted (Park et al., 2016). Because coastal basins are relatively isolated, salinity levels in those basins are highly dependent on the difference between precipitation and evaporation as

well as runoff (Kelble et al., 2007). Anthropogenic alterations that have diverted the natural flow of freshwater away from Florida Bay have dramatically decreased the amount of runoff contributing to the net freshwater flow entering this system (Kelble et al., 2007) thus at times, increasing salinity levels. Today, more than 45% of freshwater input comes from direct rainfall (South Florida Water Management District, 2016), while very little is received from the Everglades. Moreover, this has compromised many estuarine species utilizing this habitat due to physiologically constraints that hinder survival in hypersaline conditions. For example, studies have shown that massive sea grass die-offs have occurred in Florida Bay due to hypersaline conditions. This is largely attributed to this complex biological systems inability to adapt to rapid environmental changes (Cole et al., 2018). Furthermore, because seagrass is a biological base for many aquatic species, this places the entire bay as well as the American crocodile, at risk to any further anthropogenic activities that would further restrict freshwater flow to this ecosystem.

3.2 Mangroves

3.2.1 Climate Change

Alissa Ralston

Coral Reefs: Due to an increase in water temperature and an increase in ocean acidification caused by climate change, the coral reefs are in a highly vulnerable state (Bennett, 2018). Because of the increase in ocean acidification can impact corals by corroding preexisting skeletons and weakening the structures (Bennett, 2018). This makes them especially vulnerable to erosion from wave action and being eaten by the coral fish (Bennett, 2018). Studies also show that coral larvae have a hard time finding a place to settle and grow (Bennett, 2018). Rise in sea level temperature will make the coral more susceptible to disease, and if they were to recover they would be in a severely weakened state. This threat to the coral reefs poses a problem for the mangroves because a strong and healthy coral reef provides the first line of defense for mangroves against waves, this can also prevent some unwanted inundation along the banks that would otherwise kill the mangroves (Bennett, 2018).

Precipitation: As discussed in Section 2.1.3, droughts are expected to increase in frequency and intensity (Nungesser, 2015). This will be accompanied by peat loss and an increase in carbon emissions (Nungesser, 2015). In areas where droughts occur, studies show that mangroves do not germinate. This suggests that areas in low sediment moisture do not create

favorable conditions for mangroves to settle and grow. While there may be periods of high water occurrences, precipitation is expected to decrease by 10% (Nungesser, 2015). This means that droughts are expected to become more harsh and longer droughts (Nungesser, 2015).

3.2.2 Sea Level Rise

Kayla Berger

Acting as an indicator and keystone species, mangroves are an important aspect to the Florida Bay ecosystem, as they provide various services such as preventing shoreline erosion, transforming, degrading, and sequestering nutrients and pollutants, and serving as nursery habitat for many commercially important fisheries (Chambers et al., 2013). However, mangroves are being depleted at a rate of 0.7-2.1% annually due to human related activities such as sea level rise (SLR). SLR could result in the loss of up to 15% area of mangroves in the Florida Bay (Chambers et al., 2013). Because of this, salt water intrusion and inundation can affect soil microbial activity in the Florida Bay. Microbes regulate carbon balance in the peat that mangroves grow from. Chambers et al. (2013) discussed the effects of a +15 ppt increase in salinity and an 8 cm decrease of shoreline due to erosion, and found that the peat which supports mangroves are likely to collapse due to entrapment of carbon.

3.2.3 Human Impacts

Rachel Case

Population growth and human related activities have had varying impacts on Florida Bay's mangrove habitats. Mangroves are saltwater tolerant but grow best in areas where freshwater mixes with seawater. Freshwater is a physiological requirement, while saltwater is an ecological requirement. Saltwater is not required for growth, but because freshwater plants grow faster, resulting in interspecific competition, estuaries are an ecological benefit to this species (U.S. Fish and Wildlife Service, 1999). Anthropogenic freshwater extraction and alterations in the natural flow of freshwater to Florida Bay has compromised this estuarine benefit, thus decreasing this species population size and distribution (U.S. Fish and Wildlife Service, 1999, Odum and Johannes, 1975). The preferred salinity range for mangroves has been documented as no more than 0-40 ppt (U.S. Fish and Wildlife Service, 1999). However, salinity levels across basins in Florida Bay often exceeded 40 ppt (U.S. Fish and Wildlife Service, 1999) due to

reduced runoff and higher rates of evaporation over rainfall. Because mangroves can migrate when challenged with harsh environments, often times, their vulnerability to salinity does not compromise population size and distribution. However, human population growth has drastically altered and decreased the costal space available to this species for migration due to urban development (U.S. Fish and Wildlife Service, 1999) (see Section 2.4) . As mangroves push back against the harsh conditions posed by freshwater extraction and hypersaline conditions, they are met with highly developed coastal regions that inhibit migration making this species highly vulnerable to the degradation of coastal land space. For example, it can be seen that mangroves have begun to migrate westward in parts of the Everglades, but migration has been halted in southeast Miami-Dade County in response to the L-31E levee.

3.2.4 Invasive Species

Lena Midgette, Fallon Woolford, Austin Greenhill

Many plant species are posing threats to the native species. The Australian pine is an evergreen tree that is native to Australia, Southeast Asia, and South Pacific islands. The species was introduced to Florida in the 1890's and since then, the expansion of this pine is commonly found in areas that have been disturbed by people and natural events. The species threatens native Southern and Central beach plant communities where storms have degraded beaches and destroyed existing native plants. The Australian Pine also promotes beach erosion, interferes with crocodile and sea turtle nest construction, and provides little to no habitat for critical wildlife of threatened or endangered status (Florida Fish and Wildlife Conservation Commission, 2017). Another invasive plant species is a medium sized shrub, native to Brazil and Paraguay, known as the Brazilian Pepper Tree. Introduced in the 19th century, the invasive breed occupies more than 283,280 hectare in Southern and West Central Florida. The areas inhabited by the breed of plant are generally adjacent to the mangroves resulting in competition for space and resources with the mangroves. The Pepper Tree poses threats to native plants and wildlife in a sense that the colonization of the species creates densely closed canopy forest of Pepper Trees as well as poor habitat conditions for the native wildlife (Florida Fish and Wildlife Conservation Commission, 2017). Within southern Florida a large die-off of seagrass, reaching about 16,000 hectare, due to the invasive species of cattails has occurred. The cattails thrive in high-nutrient ecosystems and due to excess phosphorus the cattails are thriving rapidly (Orem, 2009). Seagrass

is a key components for feeding, foraging, and living areas for fish species that are vital food sources to crocodiles (Mcginnis, 2017).

3.3 American Crocodile

3.3.1 Climate Change

Alissa Ralston

The sex of crocodiles, like turtles, is determined by temperature (National Park Service, 2017). For a nest to be viable, it has to be at least 27.78 degrees Celsius (National Park Service, 2017). For a crocodile to be female, the temperature should stay between 27.78-31.1 degrees Celsius (National Park Service, 2017). When the temperature reaches 31.67-33.3 degrees Celsius it will be male (National Park Service, 2017). This is an issue because if the temperature rises to where only males are produced, it will cause a drastic decrease in population once they reach sexual maturity.

3.3.2 Sea Level Rise

Kayla Berger

Distribution and abundance of the American Crocodile (*Crocodylus acutus*) in the Everglades National Park is dependent on timing, amount, and location of freshwater flow (Green et al., 2012). The salinity in some regions of the Florida Bay in the Everglades National Park has been found to exceed 40 ppt, which is not a suitable environment for crocodiles (Mazzotti and Cherkiss, 2003). As freshwater flow continues to decrease due to urban development and climate change, there currently will not be enough freshwater to balance out the salinity levels that sea level rise will bring to the bay due to saltwater intrusion. Juveniles, in particular, are most sensitive to high salinity levels, leaving the survival rate for this stage of development extremely vulnerable (Richards et al., 2004). As salinity levels increase, juvenile crocodiles become less likely to survive as they reach their physiological limit to tolerate the changing water conditions. The lower survival rate of juveniles will mean less crocodiles reaching sexual maturity to successfully reproduce and continue to grow their population (Richards et al., 2004).

American Crocodile nesting sites are also projected to disappear due to inundation and erosion from sea level rise (Mazzotti, 1989). As two thirds of nesting sites of the American

Crocodile occur in the Everglades National Park sandy shorelines, successful nesting areas will become extremely scarce in Florida Bay as water levels rise.

3.3.3 Human impacts

Rachel Case

The American Crocodile has been strongly impacted by human population growth and urban development. Although the number of crocodiles nesting in the southern part of Florida has increased since 1975 due to conservation efforts, the ongoing development of coastal areas has stunted this growth significantly in more recent years (Mazzotti and Cherkiss, 2004). This decline is directly related to the ecological habitat required for the promotion of stable populations and its relation to Florida's most popular areas. For example, historical distribution of the American Crocodile occured throughout all of Florida Bay. However, the desire many people have to live near coastal areas has restricted present day distribution of this species between southern Biscayne Bay and Cape Sable in Everglades National Park (Moller et al., 2000). The main vulnerability with respect to urban development for the American Crocodile lies in the continued diminishment of suitable nesting sites for the accommodation of rapid human population growth. If the number of eggs being laid decreases significantly, than the number of crocodiles making it to full maturity decreases significantly. Moreover, crocodiles that do make it to full maturity are then faced with habitat degradation, sea-level rise, and climate change.

3.3.4 Invasive Species

Lena Midgette, Fallon Woolford, Austin Greenhill

Within the Florida Everglades, 27 invasive species have been observed (Florida Fish and Wildlife Conservation Commission, 2017). These problematic species are not only posing a threat to the overall Everglades environment, but have a direct impact on the main plant communities and crocodile population. The Burmese python is a constrictor native to Southeast Asia. These reptiles consume a wide range of mammals and birds. Pythons also occasionally prey on American alligators (Dorcas, 2012), which may lead them to target crocodiles in the future. The introduction of pythons into the system coincides with reductions in small and medium sized mammal populations where pythons have been documented recently (Dorcas, 2012). The pythons are subsequently competing with the crocodiles as the top predator forcing a

strain on food sources. The Argentine black and white tegu was introduced to the ecosystem in Southern Florida by pet trade and established breeding programs (Pernas et al., 2012). Tegus are one of the largest lizard species in the Western hemisphere. Their diet consists of vegetation and small animals, leading to a competition for food with the American crocodile. Tegus pose another threat to the crocodile population by consuming eggs directly from the nesting site. They are now considered the main predator to the eggs (Mazzotti, 2012).

4 Foresight for Joe Bay and the American Crocodile:

4.1 Climate Change: Sea Surface Temperature and Ocean Acidification

Chase Garrison

Donner (2009) discusses several scenarios regarding future effects of anthropogenic CO_2 emissions on ocean warming. Simulated climate models were generated using the Geophysical Fluid Dynamics Laboratory. The "business-as-usual" scenario is based on the rate of released CO_2 emissions staying at their current levels and projects atmospheric CO_2 concentrations of at least 700 ppm by 2100 with a 1.9 to 2.4ºC average regional increase in sea surface temperature (SST). The mitigation scenario is based on curbing CO_2 emissions low enough to keep atmospheric CO_2 between 500 and 700 ppm by 2100, which is projected to cause a 1.1 to 1.5ºC increase in average regional SST by 2100. The "commit" scenario is based on ending future CO2 emissions to keep atmospheric CO_2 concentrations below 500 ppm, which projects an average regional SST increase of 0.4 to 0.6ºC by 2100 (Donner, 2009). Hurricane and storm intensities are projected to increase under all Representative Concentration Pathway (RCP) scenarios included in the Intergovernmental Panel on Climate Change Assessment Report 5 (IPCC AR5) (IPCC, 2015).

In addition to warming ocean temperatures, the ocean also absorbs CO_2 from the atmosphere which causes ocean acidification. Acidity refers to the concentration of Hydrogen ions in a solution; the higher the concentration of Hydrogen ions, the lower the pH and the more acidic a solution is. Since the Industrial Revolution approximately 30% of CO_2 emissions have been absorbed by the global ocean causing a 0.1 decrease in pH which corresponds to a 26% decrease in acidity as discussed in Section 2.1.2 (IPCC, 2015). Climate Models used by the IPCC (2015) predict further increases in ocean acidification under all RCP scenarios, but with a slight recovery mid-century under RCP2.6. The RCP scenarios correspond with the amount of future

anthropogenic greenhouse gas emissions and include RCP2.6 (stringent mitigation), RCP4.5 and RCP6.0 (intermediate scenarios), and RCP8.5 ("business-as-usual"). The ranges for decreases in ocean pH for each RCP scenario are as follows: RCP2.6: 0.06 to 0.07 (15 to 17% increase in acidity); RCP6.0: 0.20 to 0.21 (58 to 62%); RCP8.5: 0.30 to 0.32 (100% to 109%) (IPCC, 2015).

Along with increasing SST and ocean acidification, global mean surface temperature is projected to increase as well. The future projections for mean surface temperature increases by 2100 compared to 1986-2005 are 0.3 to 1.7ºC for RCP2.6, 1.1 to 2.6ºC for RCP4.5, 1.4 to 3.1ºC for RCP6.0, and 2.6 to 4.8ºC for RCP8.5 (IPCC, 2015).

Increasing SST and surface temperatures are likely to have significant consequences on species in South Florida. Disruptions of food chains as well as loss of coastal nursery locations and habitats could cause reductions in populations and possible extinctions. This could potentially decrease food resources for the American Crocodile (FWC; Impacts on Florida's Fish and Wildlife, 2018). Small mammals and marine species will likely be vulnerable to population declines and possibly extinctions due to increasing SST and surface temperatures, and increasing SST will likely compound ocean acidification risks in marine species (IPCC, 2015). These species are significant food sources for both juvenile and adult American Crocodiles according to U.S. Fish and Wildlife Service (1999b), which means reducing populations and/or extinctions could negatively impact the American Crocodile Species. In terms of the American Crocodile's ability to adapt and migrate to new habitats, their ability to survive in both fresh and brackish water as well as in higher temperatures should allow them to increase their geographic range (Perez et al.,2017). The primary future threats are loss of nesting locations from coastal development and beach erosion as well as the fact that as temperature increases, more male crocodiles will hatch instead of females which add to the population (Perez et al., 2017; National Park Service, 2017).

Increasing ocean acidity could also potentially impact American Crocodiles. Ocean acidification effects organisms that create calcium carbonate shells, including coral reefs which are an important line of defense from storms/hurricanes for the mangroves and coastal areas that provide habitats and nesting sites for American Crocodiles. Coral reefs are also affected through increasing ocean temperatures since algae that lives in symbiosis with coral and is necessary for survival disassociate when ocean temperatures are too high, causing coral bleaching and deaths of reefs. The projected increases in ocean acidification and ocean temperatures as stated in the

RCPs from IPCC (2015) will likely cause coral bleaching and possible death of coral reefs which will remove a natural defense for coastal habitats from increasing storm intensities which American Crocodiles rely upon.

Taking all of these climate change factors into account regarding the potential futures of the American Crocodile, their population is at risk to these changes. It is probable that increasing SST and mean surface temperatures will cause changes in behaviors, geographic ranges, etc. for many species. Many species such as plants and small mammals are likely to be unable to shift their geographic ranges at a rate that will keep up with rates of climate change impacts, possibly leading to extinctions of many species (IPCC, 2015). These changes along with behavioral changes such as timing of plants blooming, animals breeding/giving birth, etc. may affect biodiversity through extinction or reduced population levels, which would disrupt food chains and food resources for American Crocodiles (FWC, 2018c). Although the American Crocodile is able to live in warmer temperatures and fresh or saltwater and could potentially extend their geographic range north according to Perez et al. (2017), they will still need suitable habitats to live and nesting sites for their eggs. Increasing ocean acidification and SST will likely cause coral bleaching and death to coral reefs that protect the Florida coastline from the increasingly intense precipitation events and hurricanes as projected in IPCC (2015). Increases in storm intensities in terms of wind speeds and amount of precipitation along with loss of protection from coral reefs will leave coastal areas that American Crocodiles rely on for habitat/nesting sites vulnerable to erosion, and increasing human populations in Florida will further reduce these areas (UCF, 2017). As surface temperature continues to increase, the number of male crocodiles hatching as opposed to females will continue to increase, leaving less females to propagate the species (National Park Service, 2017).

This multitude of factors severely threaten the potential future of the American Crocodile in Florida. Under the stringent mitigation scenarios to reduce greenhouse gas emissions and rates of climate change as described in Donner (2009) and IPCC (2015), the American Crocodile may be able to adapt to these climate change threats if conservation efforts are made to establish habitats and nesting sites in areas north of their current range. Under the intermediate and business-as-usual scenarios described by Donner (2009) and IPCC (2015), it is likely the American Crocodile will be unable to adapt at a fast enough rate to survive in Florida.

4.2 Sea Level Rise

Angela Kennedy

A spectrum of scenarios for sea level rise should be considered when developing management plans for the mitigation of impacts on the American crocodile population. This will help support the adaptation of the crocodile to the loss and change of current wetland habitat. Warming global temperatures are contributing to sea level rise, and sea level rise is contributing to an increasing rate of chronic inundation in crocodile habitat. This is leading to further erosion and habitat loss (Mazzotti and Cherkiss, 2003).

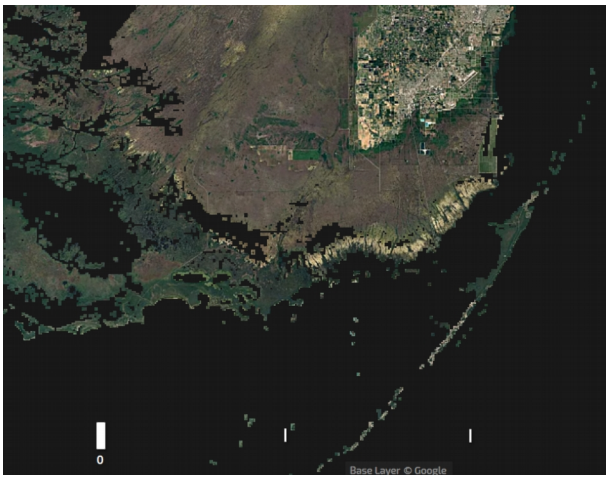
In a high-risk scenario, the Union of Concerned Scientists (UCS) determined a possible global sea level rise of 2.0 m above the 1992 sea level by year 2100. This is only one high risk scenario (see Section 4.3). The sea level rise could be significantly higher, such as 3.0 m to 5.0 m by year 2100 and up to 15.0 m by year 2500 (Dennis and Mooney, 2016). UCS's determination of a 2.0 m sea level rise assumed rising carbon emissions and rapid ice sheet loss (Spanger-Sieg et al., 2017). Sea level would have completely inundated the Everglades National Park and the current crocodile habitat (Earthtime, 2018). Any established crocodile habitats in the more northern area of Florida Bay would be at very high risk due to being in the same proximity as human development, higher rate of flooding during storm surges due to the large wetland loss, and higher inundation by sea water affecting suitability of habitats for their nests and juveniles. At a sea level rise of this rate, the number of crocodile nests failed due to inundation per year would quickly increase without ideal preventative measures. For example, creating more elevated, protected areas for the crocodiles to nest that would be less likely to flood would help support successful crocodile nest numbers. In addition, further research to collect data on the success of crocodiles to establish successful nests in more northern areas would be beneficial. The ability of the crocodiles to migrate and adapt to the loss of habitat would significantly rely on the accelerated growth and stability of the American crocodile population and the growth and development patterns of the human population. As a reference, figure 4.2 shows nesting sites and sightings of the American crocodile in Southern Florida historically and as of year 2004. There would be a need of a higher number of successful nests produced between 2020 and 2035 because crocodiles do not reach reproductive age until about 10 years or they are 2.5 m in length (Fishman and Mackinnon, 2014). The success rate of juveniles reaching reproductive age would also be a major factor. Juvenile predation and juvenile food source will be limiting factors. With

the increasing salinity potentially leading to decreasing fish density, this could pose a challenge to juvenile survival.

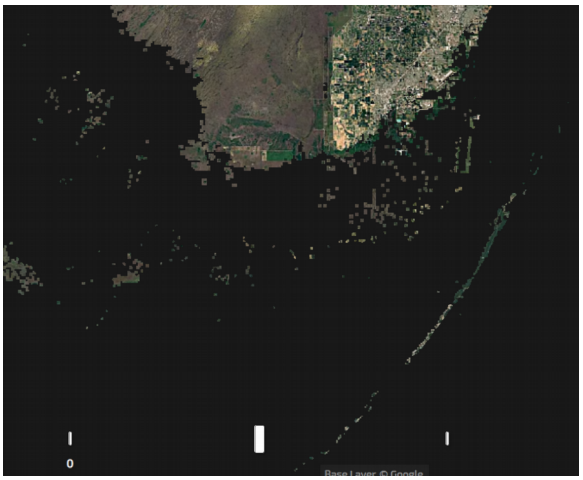
In an intermediate-risk scenario, the UCS assumed a moderate ice sheet loss and determined a possible sea level rise of 1.2 m above the 1992 sea level by year 2100 (Spanger-Sieg et al., 2017). In this situation, the rate of crocodile nest failure per year would still increase significantly due to inundation and saltwater intrusion, but the northern portion of the Everglades National Park would not be completely inundated by 2100. About 20 to 25% of the Everglades National Park would not be completely inundated. This area, if managed and protected effectively, could become a new crocodile nesting area. However, there would still be a high risk of inundation due to the loss of most of the wetlands. The success of this nest site development would heavily rely on nest building at more elevated locations and accelerated reproductive success and juvenile survival success between 2020 and 2050. This would allow for a population growth trend that would develop a more resilient population in southern Florida (National Park Service, 2017).

In a low-risk scenario, the UCS assumed that sea level rise is minimally influenced by ice sheet melting and determined a possible sea level rise of 0.5 m above the 1992 sea level by year 2100 (Spanger-Sieg et al., 2017). This would be a best-case scenario because the rate of sea level rise increase would be at a much more manageable rate. The mangroves, which support development of ideal nesting and nursery area for the crocodiles would have a higher chance to migrate north. There would be more time to develop and implement short-term and long-term plans to protect and support the growth of the crocodile population. With a readily accelerated successful nest rate and juvenile survival rate between 2020 and 2060, this would allow for a population growth that would support the crocodiles' resilience (National Park Service, 2017). Figure 4.1 shows three different maps of Southern Florida. The first map in the figure shows the current sea level. The second and third map demonstrate where sea level could be at a sea level rise of 0.7 m and a sea level rise of 2.1 m.

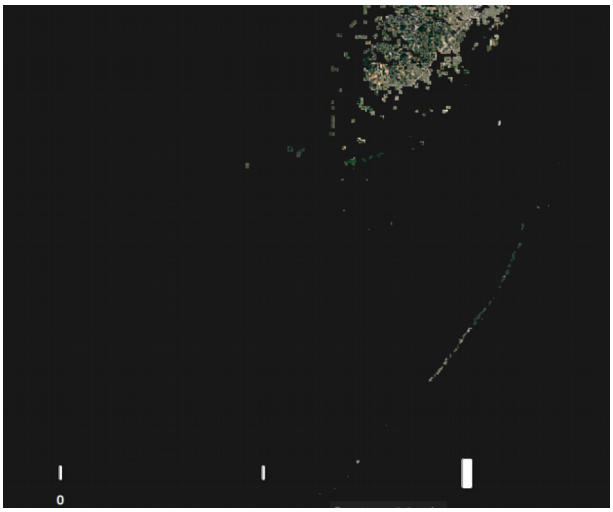
Evidence shows that a sea level rise of 2.0 m or higher is increasingly more likely. The rate of ice melting of the Antarctica and Greenland ice sheets has significantly accelerated (Pierre-Louise, 2018). The melting rate has more than tripled since 2007. This factor combined with further ocean warming contributes to higher rate of sea level rise. Sea level could rise well over 3.0 m to 5.0 m by 2100 (Pierre-Louis, 2018).



Current Sea Level



Low-risk scenario: 0.7 m sea level rise



High Risk Scenario: 2.1 m sea level rise

Figure 4.1: These maps represent the current sea level in southern Florida, and two possible outcomes of sea level rise based on a 0.7m sea level rise and 2.1 m sea level rise. All three maps show the same area (Earthtime, 2018).

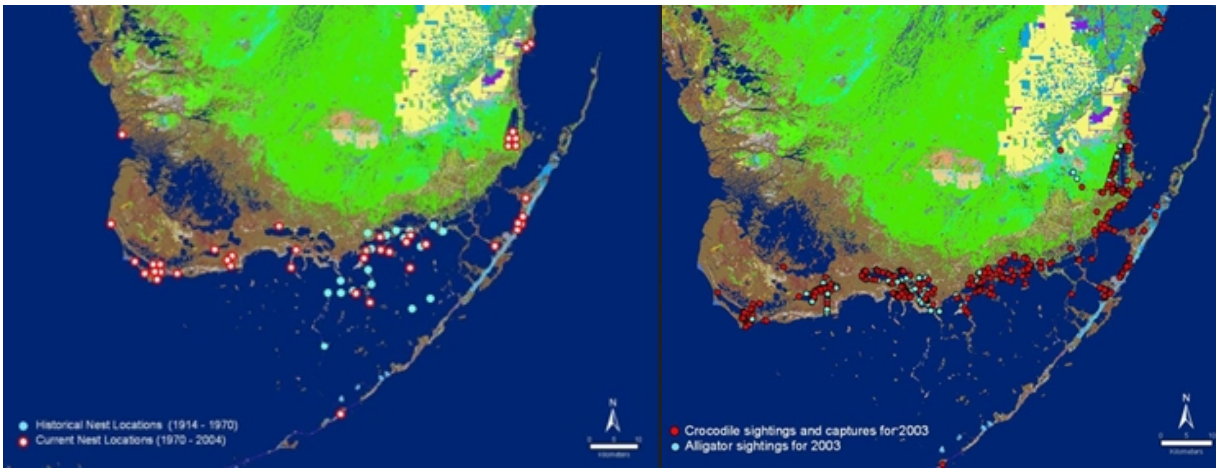


Figure 4.2 The map on the left shows historical and current crocodile nest sites as of 2004. The map on the right shows crocodile sightings and captures for 2003 and alligator sightings for 2003. This provides a basis for developing possible scenarios (Mazzotti et al., 2004).

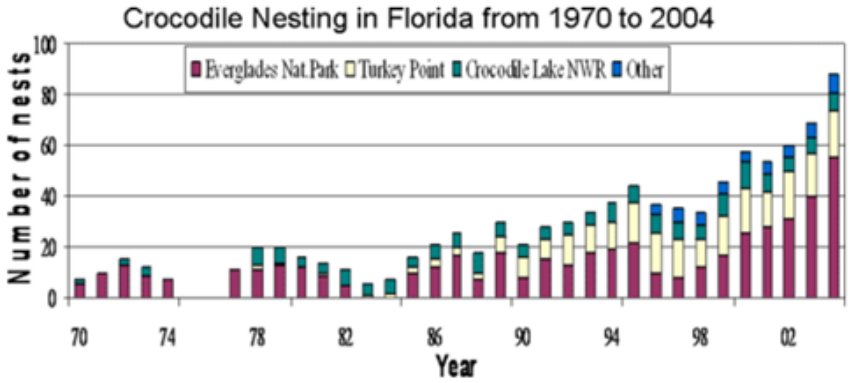


Figure 4.3. This graph shows the crocodile growth trend from 1970 to 2004. This can provide a basis for crocodile population growth and reproduction patterns in foresight development (Mazzotti et al., 2004).

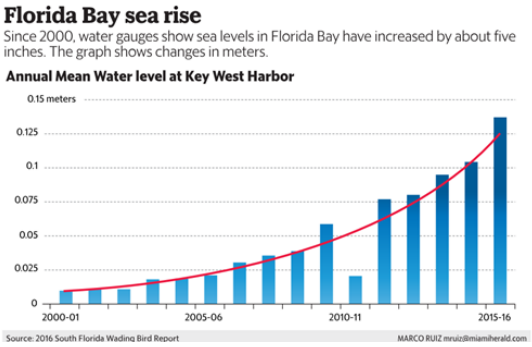


Figure 4.4 This graph shows the positive trend of sea level in Florida Bay from 2000 to 2016. It demonstrates that sea level has been rising at an accelerated rate in the last 6 years. This can be utilized to build possible scenarios for sea level rise (Baranski and Cook, 2017).

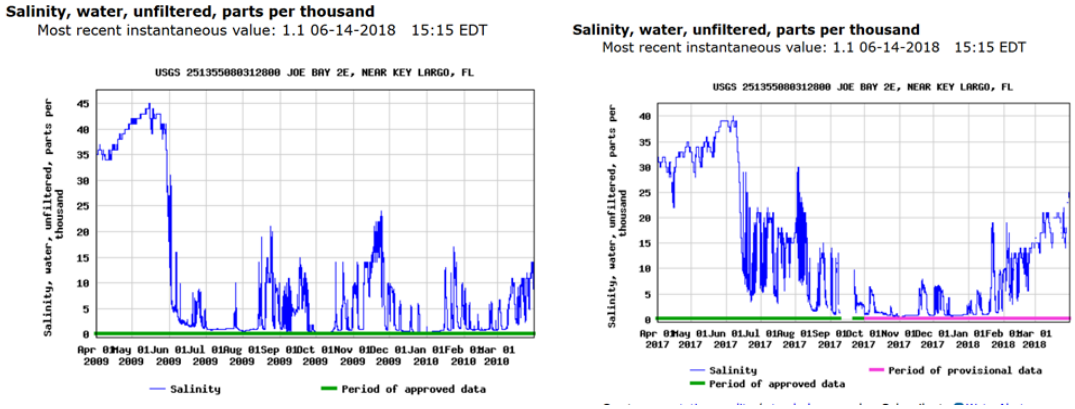


Figure 4.5 These graphs show the salinity changes from the beginning of the wet season to the end of the dry season. This is correlated with the nesting patterns of the crocodile. Specifically, the crocodile eggs are incubated for about 85 days, until they hatch in late July to early August. This span of time is when the salinity in Joe Bay trends the lowest due to it being towards the end of the wet season. This is ideal for juvenile crocodiles to thrive since they do not tolerate higher salinity as effectively as adult crocodiles (National Park Service, 2017). The graph on the left shows the time frame of April 2009 to March 2010. The graph on the right shows the time frame from April 2017 to March 2018. Compared to the season cycle of 2009 to 2010, the season cycle of 2017 to 2018 shows the salinity dropping to low levels in September and October instead of July and August. There is also a short span of time with low salinity in 2017 to 2018 compared to 2009 to 2010 (USGS, 2018).

4.3 Socio-economic Foresight

Rachel Case

With estimates of population growth ranging around 36 million by 2060 (UCF, 2007), it is thought that 2.8 million hectare of additional lands could be converted to urban uses. This means that Florida could lose 1.1 million hectare of existing agricultural lands, along with 1.1 million hectare of native habitat and more than 809 thousand hectare within one mile of existing conservation lands (UCF, 2007). The negative impacts that urban development has had on the Everglades National Park as well as the American Crocodile have become more evident over the years. However, what is not clear, is the future trajectory of the Everglades National Park and the American Crocodile in the face of population growth, socio-economic activity, and climate change. Here, two scenarios are taken into consideration, both of which are heavily dependent on the rate of sea level rise as well as any thresholds that may exist within the system that could lead to rapid transitions that would restrict adaptation time.

Current estimates of global sea level rise could be drastically underestimated, and a plausible worst-case global sea level rise scenario should at least include a range of 2.0 m to 2.7 m by 2100 (NOAA, 2017). The first scenario discussed in this section will take into consideration a local sea level rise of 3.0 m by 2100 for Florida Bay. A local sea level rise of 3.0 m could lead to the inundation of the southern portion of Florida extending all the way through to Lake Okeechobee (Figure 4.6). The US Census Bureau reports that currently, Florida's least dense areas of human population occur right above and to the west of Lake Okeechobee, while denser areas occur on the coasts. With estimates of dramatic population growth for Florida (see Section 2.4) and the idea that when faced with sea level rise and extreme weather events humans inhabiting Florida's coasts will migrate, it would be beneficial for stakeholders to take into consideration that the areas surrounding Lake Okeechobee could become heavily populated by 2100. Figure 4.6 shows that a local sea level rise of 3.0 m could reach Lake Okeechobee, meaning this ecosystem has potential to become the new estuarine ecosystem that the American Crocodile depends so heavily on. Section 4.7 suggest that the American Crocodile is resilient to sea level rise and temperature rise with the expectation of temperature-dependent sex determination. Considering updated policy and management actions are set into place by 2100 counteracting the effects that population growth and migrations could have on Lake

Okeechobee's surrounding undeveloped areas, there is reason to believe that the Everglades, along with the American Crocodile, could survive a northward migration given enough space is protected and left undeveloped for this transition. Lake Okeechobee could become the new Florida Bay.

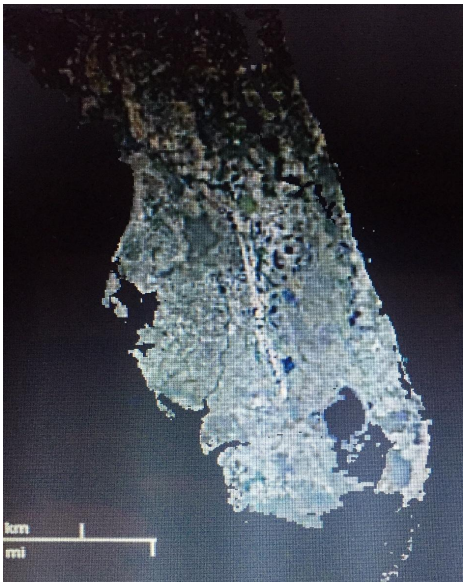


Figure 4.6 This figure represents a sea level rise scenario for Florida of 3.0 m. This map shows inundation all the way through the southern tip of Florida to Lake Okeechobee. This scenario is presented under a 1.5 degree C global temperature rise. Map was created using the tool available at http://www.earthtime.org.

The next scenario takes into consideration what USC (2017) calls a "high- risk" scenario and assesses it as an intermediate-low scenario based on information outlined in the former assessment. Under this scenario, global sea level is projected to rise 2.0 m by 2100 (UCS, 2017) and a local sea level rise of 2.0 to 2.5 m by 2100 is considered. A local sea level rise of 2.0 to 2.5 m could lead to the inundation of the Florida Keys and 50% of the Everglades National Park. Figure 4.7 represents a global sea level rise of 2.1 m due to the constraints of the mapping tool used, but this figure does give a general visual representation of what this scenario could look like. In this scenario, human related mass migrations within Florida are considered with respect to central Florida and Lake Okeechobee's surrounding undeveloped areas. It could be assumed that when faced with climate related stress, such as sea level rise and extreme weather events, people living in the Florida Keys and close to the coasts, will want to migrate, but settle as close to their former homes as possible. As mentioned in the previous assessment, that space will be most accessible in areas surrounding Lake Okeechobee. Given that 50% of the Everglades

remains above water, it may be possible to accommodate these mass migrations as well as projected human population growth (see Section 2.4) if stacked housing systems are taken into consideration. With stacked housing systems, more people can fit per hectare of land. However, it would be crucial that policies and sustainable efforts are set in place for the protection of Lake Okeechobee's waters. These policies and sustainable efforts would include protection from soil erosion and runoff that could lead to decreased impaired water quality and eutrophication. As for the American Crocodile, there is evidence that supports comfortable living accommodations can be found in Biscayne Bay given there is enough space open for nesting and adequate amounts of clean freshwater are delivered (Cherkiss et al., 2011). Note, this particular scenario is heavily dependent on the removal of the L-31E levee to allow space for the migration of mangroves given their importance to the American Crocodile (U.S. Fish and Wildlife Service, 1999) (see Section 3.2.3).

Figure 4.7 This figure represents a sea level rise scenario for Florida of 2.1 m due to the constraints of Earthtime.org. This map shows inundation of the southern tip of Florida. This scenario is presented under a 1.0 degree C global temperature rise. Map was created using the tool available at http://www.earthtime.org.

5. Decision-Making for Joe Bay

5.1 Climate Change

Austin Greenhill

Understanding how stakeholders and federal agencies, such as the Everglades National Park, work together is vital to the management of Joe Bay. The importance of the relationship is magnified as natural resources provide the American crocodile with possible hospitibile grounds.

The stakeholders involved with the Everglades National Park help demonstrate the feelings and emotions associated with surrounding communities and various groups that they have about the ecosystem and the services it provides (Choe, 2016). Other stakeholders included are the US Environmental Protection Agency, South Florida Water Management, The Florida Climate Alliance, tourist, business owners, fishers, farmers, and locals. All stakeholders can be related through the impacts of climate change, movement of crocodile, and even decrease in species diversity of an area, but a migration management plan for the crocodiles as climate change rates increase will be needed for the continued survival of the species in South Florida. As climate change's effects continue the crocodile will have no choice but to move into urban developed territory. Home-owners, locals, and businesses would have to decide whether it is worth it to stay or move since crocodiles will have started to overlap environments. For example if by 2100, the business as usual scenario for climate change were being used a 1.9-2.4 degree C rise in temperature would cause more males hatchlings than female hatchlings to be born lowering reproductive chances. In result of this low mating chance the males crocodiles began to migrate in search of a mate, but has ended up in a hotel pool. The decision makers need to make a plan for the management of the crocodiles nesting pattern to make sure numbers stay even between gender and within plenty of natural resources.

5.2 Sea Level Rise

Angela Kennedy.

Sea level rise projections increase the need to develop plans to continue protection and support of the Florida crocodile population. Mitigation and adaptation strategies for facilitation of successful habitat and nesting sites for the American crocodile involves the US Fish and Wildlife Service, the National Park Service Department of Interior, Fish and Wildlife Conservation Commision, the public in the Southern part of Florida, the Florida power and light company, the governor of Florida, and state parks like the Crocodile Lake Refuge and Pennekamp state park. The public includes residential and business developments, farmers, vacationers, and fisherman. As the crocodile population growth and migration is supported by conservation efforts, potential viable nesting areas could occur in closer proximity to developments or in already developed areas. For example, Turkey Point power plant has become a main nesting area for crocodiles due to good nesting conditions (Mazzotti and Cherkiss, 2003)..

Increased education and awareness about the crocodile for the public will be necessary as crocodile interactions in developed areas could occur more. The Florida public and power companies will have a main role in deciding what areas to protect and conserve for viable nesting areas. This will challenge those who support further development over habitat protection. The Fish and Wildlife Conservation Commission, the US Fish and Wildlife Service, and the National Park Service and state parks will be responsible for research and monitoring programs for the nesting crocodiles (Mazzotti and Cherkiss, 2003). This would provide insight to the capability of the crocodile to migrate to more northern areas of the bay, Florida, and even Georgia as sea level could rise well over 3.0 m to 5.0 m (Dennis and Mooney, 2016).

5.3 Urban Development

Fallon Woolford

The stakeholders involved in urban development can have a huge impact on the life and migration of the American Crocodile. The US Fish and Wildlife Service (USFWS), has control over the land that most of the breeding population of the American Crocodile live (USFWS, 2015). Other stakeholders in control of urban development include the home owners and general public population of Southeastern Florida, and the areas surrounding the Everglades National Park. If the public and homeowners had education on what building more houses is doing to the American Crocodile population and what importance they are to the ecosystem, they would stop developing land that should be preserved. Other stakeholders include the fisherman, commercial or recreational. Florida Bay's economy is highly dependent on sport-fisheries. Furthermore, these stakeholders, the fisherman, depend on other stakeholders like the Army Corps of Engineers, State Congress, water managers to implement ways to save the water-way from high levels of salinity that affect the fish. (Conner, 2015). Directly above the Everglades National Park is the Everglades Agricultural Area, these farmers are another stakeholder for this because the ways they deter pests from their economically driven crops has an effect on the quality of the water that is flowed into the Everglades National Park. Additionally as stated in scenarios 4.3, stakeholders would include the landowners and the legislatures surrounding Lake Okeechobee. These stakeholders would be the deciding factor in the efforts to protect Lake Okeechobee's surrounding land from further development and making a action plans to federally protect this land.

6 Options

6.1 Climate Change

6.1.1 Researching the American Crocodile's nesting patterns

Austin Greenhill

Further research should be developed on the spatial and temporal patterns of nesting habitat loss of the American Crocodile in response to climate change, to establish a management plan for migration. Steady temperatures reaching heightened climates for longer periods of time have the ability to confuse the crocodiles nesting instincts and well as skew the gender ratio of the hatchlings for more males to be present than females. Studying the spatial and temporal patterns of these animals may provide insight to a the most profitable conditions for the crocodile and where those conditions may ly. Continuing the study of the nesting habitat loss will allow plans to be made for migration of the crocodiles to areas that are least likely to be lost from climate change.

6.2 Sea Level Rise

6.2.1 A Migration Plan for the American Crocodile

Kayla Berger

According to Mazzotti and Cherkiss (2003), the lowest salinity levels occur in northeastern Florida Bay, which increases the amount and suitability of habitat for the American Crocodile. Because of the low salinity levels in this area of the Bay, as well as an abundance of mangroves also in this area, this study suggests that the man made nesting areas along Turkey Point and Crocodile Lake National Wildlife Refuge provide nearly ideal conditions for American Crocodile habitat (Mazzotti and Cherkiss, 2003). Further research should be done to continue the success of these sites for the American Crocodile. If these sites continue to show success in nesting and nursery habitat, further mitigation and adaptation plans should be made for the American Crocodile to aid in their movement to the northeastern parts of the Bay. This mitigation and research strategy is only being considered by a sea level rise of at least 1m and salinity levels if freshwater flow continues to decrease from urban development. If any plans are developed to aid in an increase in freshwater flow, suitable habitat for the American Crocodile could expand beyond the northeast section of Florida Bay.

6.3 Urban Development

6.3.1 Limited Access in Joe Bay

Fallon Woolford

The reopening of Joe Bay occurred less than 2 years ago, it is impossible to see the effects it has caused on the American Crocodile. One action plan would be to limit the access to Joe Bay now that it is opened to the public. Currently it is only open to non-motor boats, for example kayaks and paddle boarding. The Everglades National Park should keep Joe Bay the way it is currently to limit the amount of interaction in between the American Crocodile and the human species.

6.3.2: Restoration of Freshwater Flow

Fallon Woolford

In the past, freshwater would flow directly from Lake Okeechobee to the Florida Bay (figure 6.1). Now the water flows from the lake directly to the East and West Coasts. There is a restoration plan to get freshwater back into the Florida Bay and thus reduce the impact of droughts, however it would be beneficial to work on federally protecting areas around Lake Okeechobee. By using the current restoration plan (citation) opening up water flow allows human development in undeveloped lands and pushes phosphorus and pollution levels down. To preserve Lake Okeechobee it would be beneficial to take away from the urbanization that is happening in the surrounding areas. To save space for the upcoming influx of the population of people, the lawmakers, the mayor of the surrounding towns, would implement a form of stack-housing. Stack-housing would offer more space in a low-spatial area. (See section 4.3).

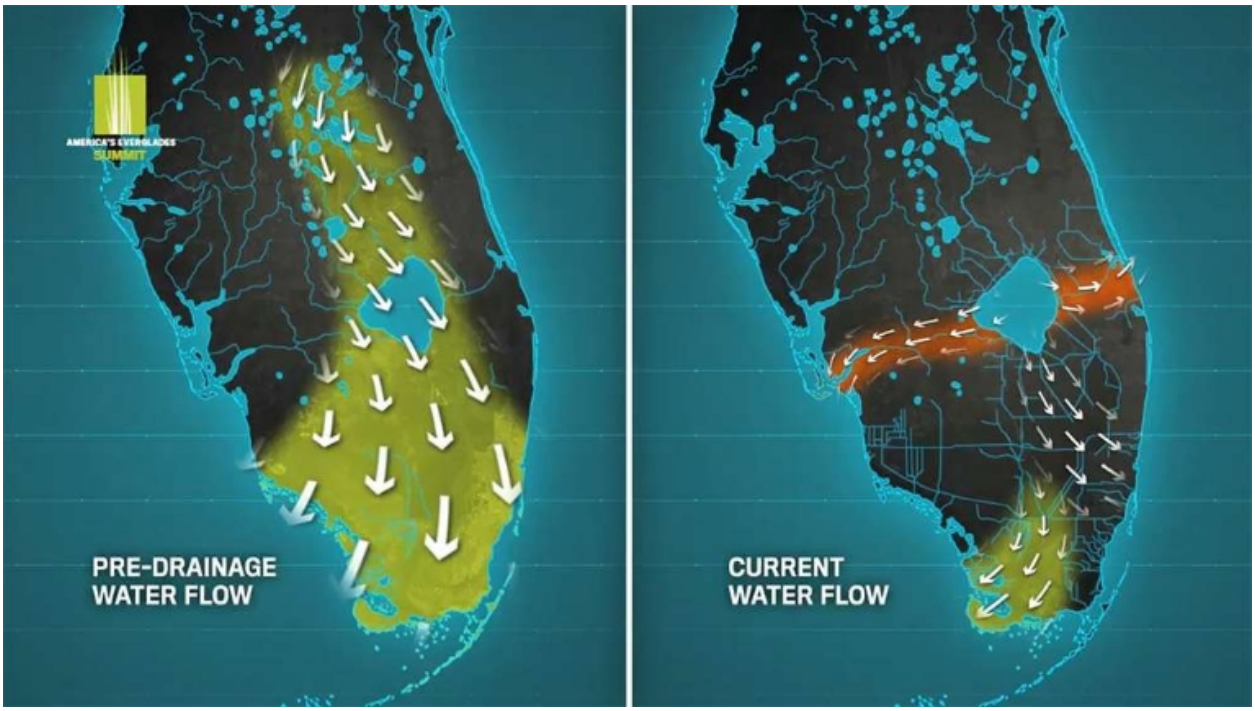


Image from the Everglades Foundation.

Figure 6.1 These maps show the historical and current water flow patterns in Southern Florida. This has an impact on water levels and salinity levels in the Everglades and Joe Bay. This affects the balance of the ecosystem.

7 Recommendations

7.1 Recommendation 1: Limited Access in Joe Bay

Lena Midgette

Based on the impacts of urban development, climate change, and sea level rise presented to be affecting the Everglades National Park and the American crocodile, there are three recommendations that should be implemented. The first is to ensure the limited access in Joe Bay while allowing for public outreach by the U.S Fish and Wildlife and the Florida Fish and Wildlife Conservation Commission, within the Florida Keys as well as Southern Florida. With the crocodiles' lifespan reaching 70 years (Mazzotti, 1997), and Joe Bays' 36 year closure, this leads to the crocodiles being unaccustomed to human presence. If access accelerates, recreational demands increase, and indirect disturbance by human activities could affect the crocodiles' behavior (Mazzotti, 2003). The limited access will allow for a decrease in the disturbance of nests and a possible increase of the survival rate in juveniles. Limited access will also decrease fishing activities allowing food security for the juvenile crocodiles. The increase in survival rate

will support crocodile population resilience and facilitate species migration should habitat loss occur due to sea level rise. Based on the foresight of sea level rise for 2.0 m, it would be necessary to implement practices to insure migration North is habitable, further research should be developed from Florida's' stakeholders on the spatial and temporal patterns of nesting habitat loss to establish a management plan for migration (Mazzotti, 2003). Identifying potential crocodile nesting habitat and mapping nesting behaviors will be useful in the developing the plan. Studying the crocodiles' food source will be important in mapping possible migration patterns.

7.2 Recommendation 2:

Austin Greenhill

A second recommendation entails taking precautionary steps toward protecting Lake Okeechobee in restoration and preservation efforts if crocodiles should relocate to other habitats due to a worst case sea - level rise scenario. Identifying potential crocodile habitats or nesting sites in areas outside of their current geographic range will be practical in developing a management plan. Upwards of one hundred plots should be examined for habitat loss due to sea level rise with essential variables of crocodile being noted at each site. Using the essential variables should expose a number of places as suitable for the crocodiles living requirements. Among more nesting site research a management plan of alike places should be created for the migration of the American crocodile through Florida.

7.3 Recommendation 3: Restore Direct Water Flow to Joe Bay

Fallon Woolford

A third recommendation would be to restore the natural water flow from Lake Okeechobee to Joe Bay. As seen in Figure 6.1 the pre-drainage flow had water from Lake Okeechobee flowing directly down into Joe Bay providing it with much needed freshwater, the current state is drastically different. Currently it flows more to the gulf, by way of Caloosahatchee River, and towards the Atlantic Ocean by way of St. Lucie River. This problem was brought on by man-made issues, like the building of homes and businesses as well as the large amount of sugar cane fields that are directly underneath Lake Okeechobee (Reid et al. 2018). In adding more water flow through pumps to the Everglades National Park by way of Lake Okeechobee the animals inhabiting it to get more freshwater. Also as stated in section 6.2.3, there would also need to be precautionary steps to be made to protect the area around Lake

Okeechobee from being developed, so that the water quality would remain well enough to benefit Joe Bay and its inhabitants.

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