The Threat of Sea Level Rise and How it Impacts First Landing State Park

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The System

First Landing State Park (FLSP) is located in the northeastern region of the Tidewater Area of Virginia. Opened in 1936 by the Virginia Commonwealth as part of the original six park system, the park conserves the natural environment and resources of the unique subtropical, temperate ecosystem. It serves as a National Natural Landmark and it provides a wide array of recreational and educational opportunities for the public (DCR, 2000). It is one of the leading Virginia State Parks in visitation numbers and economic impact for the state (Mignini, 2018).

Hazards

Anthropogenic factors including carbon gas emissions have driven climate change and global average temperature increase. Global warming affects the density of the ocean waters, which causes a steric effect that influences rapid sea level rise (Lim, et al., 2017). In addition, accelerated melting of the Greenland and Antarctic ice sheets could further impact sea level rise by year 2100. The rate of sea level rise in the 20th century has occurred 10 times faster than the rate over the last 3,000 years, and the rate in the last 25 years is significantly higher than the past 100 years. Data shows this rate is accelerating (Glick et al., 2008, IPCC, 2015). A rising sea level poses more of the threat to low-lying coastline areas, including the Chesapeake Bay area where FLSP occurs. The coastal area is more prone to coastal erosion and flooding due to a rising water table and increased storm surge effects. Salt intrusion also poses risk to the ecosystem composition. Though many species of FLSP are resilient to a wider range of salinities, prolonged higher salinity levels can have negative impacts on the system (Glick et al., 2008).

Vulnerabilities

FLSP is located in a low elevation area that hosts a unique variety of natural communities that consist of many rare, endangered, or threatened species. There are at least eight natural communities that are rare in Virginia, and two are globally rare. There are over sixty rare flora, fauna, and invertebrate species that occur in the park. This includes the rare chicken turtle and the rare carpenter frog. Many of the species are tolerant of salinity fluctuations, however prolonged inundation and flooding of seawater into the area would poses a threat to species composition in the tidal marshes, maritime swamps, and non-riverine swamps (DCR, 2000). A loss of land and habitat

due to increased flooding and inundation would also impact recreational and economic activity of the park (Mignini, 2018).

Possible Futures

With the varying factors of human activity and climate change, a spectrum of possible outcomes for global and local sea level rise and impacts should be developed to aid in management strategies for FLSP. Data and models were utilized from the 2014 synthesis report of the Intergovernmental Panel on Climate Change (IPCC), studies of the Union of Concerned Scientists (UCS), studies of the US Geological Survey (USGS), and the findings of scientists Robert Deconto and David Pollard to create the future scenarios. Carnegie Mellon University's CREATE Lab's EarthTime project that uses large global data sets was also incorporated. Specifically, three main scenarios were considered that showed impacts for a range from 0.26 m to over 15.0 m in the global average sea level rise. 70% of the coastal areas, including FLSP, could experience a sea level rise 20% higher than the global average (IPCC, 2015; Caldas et al., 2017). In all three scenarios, the ecosystem stability and recreational activity of the park was impacted.

Decision-Making

First Landing State Park operates under the guidelines of their resource management plan, which is approved and overseen by Virginia's Department of Conservation and Recreation (DCR). The park also voluntarily follows policies placed by the Department of Interior's National Natural Landmark Program and the City of Virginia Beach. To effectively address the risks associated with the threat of sea level rise on the park, the governor, city government, park staff, national agencies, and the local and visiting population need to take an active role in the development and execution of plans for mitigating the impacts of sea level rise (DCR, 2000). This is

supported by public polls in the Tidewater area showing a high public concern about local impacts of sea level rise (Institute for Environmental Education, 2011).

Possible Options

Based on the foresight concerning the hazards associated with sea level rise and the vulnerabilities of FLSP, three options to reduce the risk are developed. These options involve extending the current management practices of monitoring to also include the state of the varying ecosystems and controlling invasive non-native species. First, further research is needed to develop effective dune mapping and topographical changes in the various communities of FLSP, especially the tidal marsh habitat, dune forests, and beach and foredune areas. Second, more involved management may be necessary in maintaining the tidal marshes or wetlands and help to support the sustainability and resilience of the ecosystem, which is vital for larger natural system of the area. Thirdly, developing plans to promote land easement and acquisition in areas south and southwest of FLSP especially would help to allow for a slow transition that is needed to create more opportunity for the habitats to migrate and start to create wildlife corridors. This would help preserve the unique species compositions (Titus, 1988).

Recommendation

In analyzing the system of FLSP, as well as the challenge sea level rise poses to it and evaluating the potential impacts of three scenarios of future sea level rise, four adaptation options are provided. Further topography research of the changes on the shoreline, dune complexes, and marsh areas of the park will allow for more effective plan development. This coupled with more involved wetland restoration efforts could lead to prolonged protection of FLSP and the naturally significant ecosystems and recreational opportunities it provides can be sustained. Citizen science programs could be developed from existing educational programs at FLSP and expanded into mobile-app projects to facilitate interest in conservation efforts and scientific data collection (Klemick, 2018).

Introduction

1.1 First Landing State Park

First Landing State Park (FLSP) was originally opened as Seashore State Park in 1936. It was opened along with five other parks in the Virginia state park system. It was renamed in 1999 as FLSP to memorialize the landing of the first settlers of Virginia. The General Assembly had authorized land acquisition for the park in 1933 for recreational use, and the Civilian Conservation Corps developed the park with boardwalks, trails, cabins, and roads between 1933 and 1940. FLSP encompasses approximately 2,888 acres of secondary dunes, beaches, interdunal swales and ponds, maritime forests, saltwater marshes, and freshwater wetlands (Figure 1.1). This includes cypress swamps, live oak stands, loblolly pine forest, hickories, red maple, and black gum. Today, there are over 19 miles of trails and 1.5 miles of beach (Figure 1.2; DCR, 2010; Mitchell, 1997).

Because of the park's notable unique and diverse habitats, the park is a National Natural Landmark and is the most ecologically significant one in the Virginia Commonwealth. There are species that occur in FLSP that do not occur anywhere else in the world. For example, Kurt A. Buhlman, a research scientist with the Division of Natural Heritage, found a bug species at FLSP that the Smithsonian Institute determined to occur nowhere else in the world and is known as the Virginia Beach Bug (DCR, 2000). In addition, the park supports geographically disjunct and rare species populations. There are populations and genetic lineages of native species that are likely as old as the Pleistocene (Wright et al., 1990). Research conducted by the Division of Natural Heritage of the DCR in the 1980's and 1990's documented 7 rare vertebrate species, 37 rare plant species, and 20 rare invertebrate species. There are also 14 distinct natural communities in FLSP. Of these, 8 are rare in the state of Virginia and at least 2 are globally rare. The Interdunal Pond, Maritime Dune Woodland, Maritime Upland forest, Maritime Swamp communities and Cypress Pool communities appear to be extremely limited outside of Virginia. The variety of environmental education programs, natural habitats, and recreational activities in this unique park create the increasing appeal. The number of visitors has been increasing steadily since the early 1960's and reached close to two million in 2017 (DCR, 2000). Virginia State Parks stimulate significant economic activity for Virginia. In 2017, the total economic impact of Virginia State Parks was $239.4 million. FLSP was and is one of the top revenue

contributors to the Virginia state park system, having an economic impact of $23.5 million in 2017 (Mignini, 2018).

Figure 1.1 This is a map showing First Landing State Park in Virginia Beach, VA. The Park is identified with the blue line. From Google maps (2018).

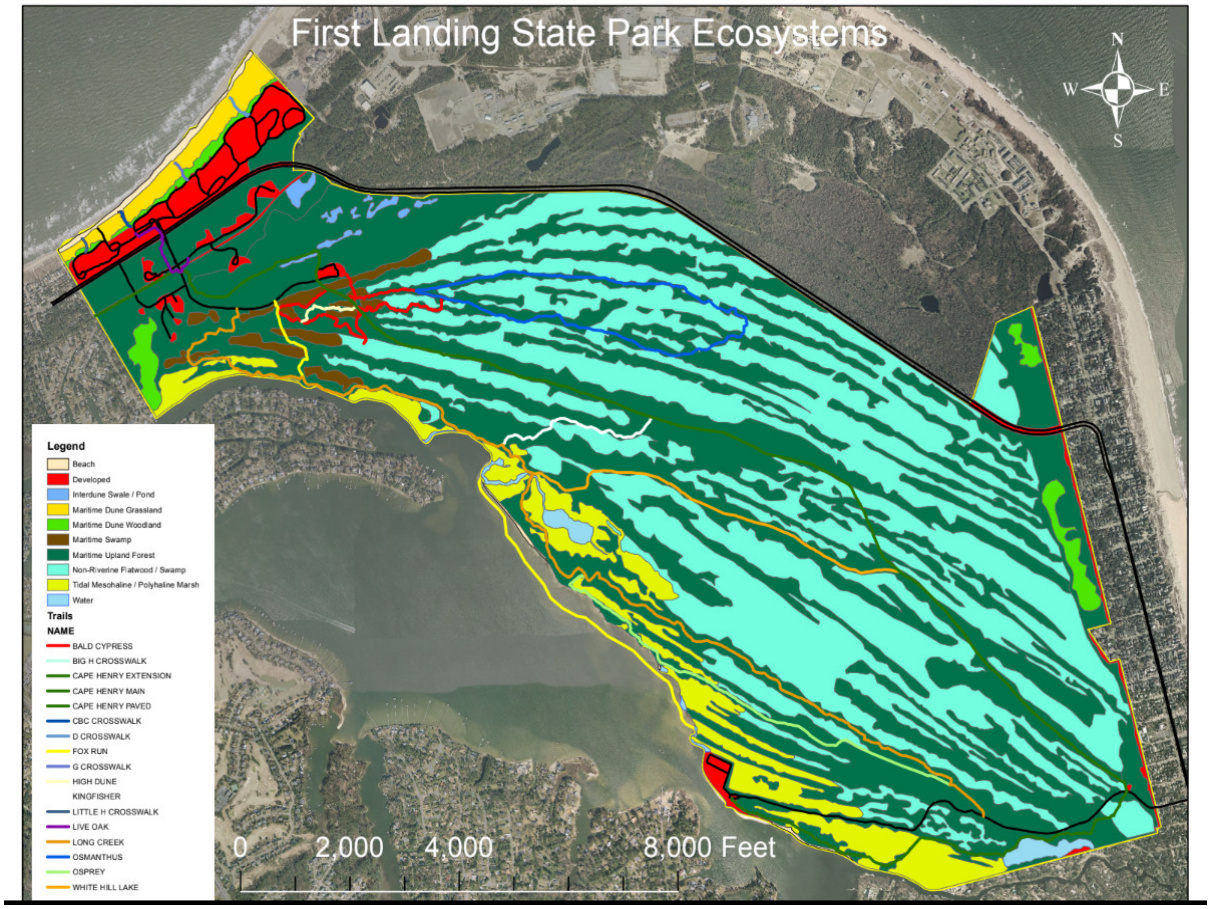


Figure 1.2 This map of First Landing State Park shows the natural communities and trails that occur in the park. From Molleen (2018).

1.2 The Challenge

First Landing State Park is part of a low-lying area within the Chesapeake Bay watershed that is threatened by sea level rise. Sea level is rising at an accelerated rate. From year 1901 to 2010, the global mean sea level rise (SLR) was 0.19 m, ranging from 0.17 m to 0.21 m (IPCC, 2015). The rate of SLR since the mid-1900's was significantly higher than the previous two millennia. Anthropogenic influences have likely affected the global water cycle and contributed to the retreat of the glaciers since the 1960's (IPCC, 2015). They have also contributed to the increased surface melting of the Greenland ice sheet since 1993 and to the Arctic ice sheet loss since 1979, and to increases in global upper ocean (0-700 m) heat content. These aspects attribute to

accelerated global sea level rise (IPCC, 2015). The West Antarctic ice sheets could disintegrate if the current rate of greenhouse gas emissions continues (Hansen et al., 2016). This could lead to a global sea level rise of at least 5.0 meters. This poses a more significant threat to coastline areas, especially that of the Chesapeake Bay due to its expansive coastline, low topography, and growing coastal population. With FLSP located near the mouth of the Chesapeake Bay, the park is very vulnerable to the impacts of SLR (Glick et al., 2008).

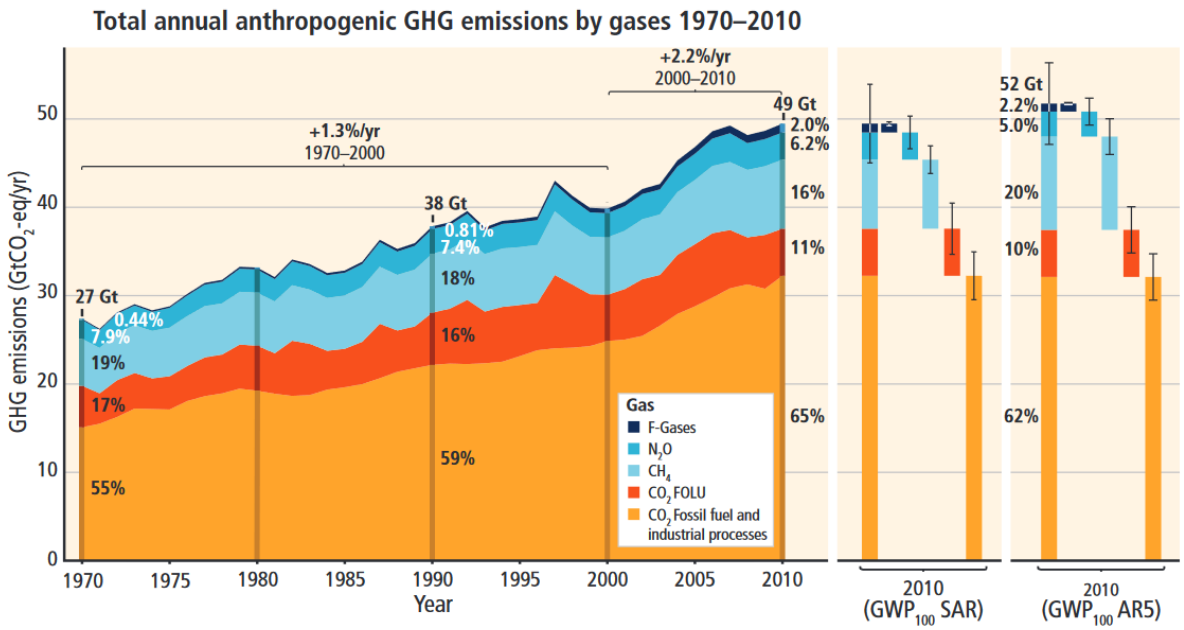
Rising sea level could alter the unique habitats of FLSP that support diverse animal and plant species and increase the risk of inundation of large portions of the park because of increased erosion rates, storm-surge effects, groundwater level changes, and saltwater intrusion (Cronin, 2013). In addition, the population of Virginia Beach increased from slightly over 350,000 people in 1990 to more than 450,000 people in July 2017 (U.S. Census Bureau, 2017). In the wake of this explosive population growth and threats of environmental changes and sea level rise, it is important to understand, document, and preserve the natural museum of FLSP and the botanical heritage of the area (Wright et al., 1990). FLSP's mission is to preserve the natural environment of this historic site while providing opportunities for recreational and educational activities. Current management practices include maintaining a healthy ecosystem by controlling public access into specific areas, monitoring sites to ensure stands of vegetation remain protected, identifying and monitoring of invasive species as well as controlling and treating for these species, and prevention of human-driven activities such as hydrologic changes and logging. Further research and understanding the full range of plausible sea level projections is necessary to develop effective mitigation plans that support the park's mission and survival of the rare species of FLSP (DCR, 2000).

2. Hazard of Sea Level Rise

2.1 Sea Level Rise and Global Trends

The climate changes and global warming that has occurred due to anthropogenic influences have driven the observed accelerated sea level rise. Post-industrial era greenhouse gas emissions have significantly increased the amount of carbon dioxide, methane, and nitrous oxide in the atmosphere. Between 1750 and 2011, the CO_2 emissions were approximately 2040 Gt, and about half of the emissions occurred in the past 40 years. About 816 Gt of the emissions have remained in the atmosphere and the rest has been absorbed in the ocean, plants, and soils. Pre-industrial values of atmospheric CO_2 averaged 280 ppm, while at the beginning of 2018 the concentration was more than 410 ppm. This is markedly higher than the full range of 180 to 300 ppm during the last 650,000 years. **Figure 2.1.1** shows a graphical representation of the accelerated gas emissions since 1970. This significant increase in greenhouse gas emissions has been correlated to the increase in global surface temperature observed since the 1950's (**Figure 2.1.2).** Since 1961, data has shown that the ocean has been absorbing more than 90% of the heat added to the climate system (IPCC, 2015). Compared to the trends from year 1850 to 1900, global temperature increase by year 2100 could exceed 1.5 ^{o}C (IPCC, 2015). During the 20th century, global mean sea level rise was about 0.19 m. The rate SLR occurred was 10 times faster than the rate over the last 3,000 years. (Glick et al., 2008)

The positive trend of greenhouse gases has caused a positive radiative forcing in the climate system and led to correlating surface and ocean temperature increase as well as sea level. The warmer ocean water causes thermal expansion (so-called steric sea



level rise), a contributing factor to SLR. In addition, the melting of glaciers and ice sheets causes changes in the albedo effect. These changes lead to warming of the land and atmosphere. The melting of sea ice changes the albedo of the ocean and increases ocean warming. This increases sea ice melting. The warmer ocean water weakens coastal ice shelfs. This leads to increased land-based glacier melting. Even if the greenhouse gas emission quantities were to stabilize, the thermal inertia of the climate system would still lead to continued temperature increase and sea level rise (Helsen, 2017; Meehl, 2005).

Figure 2.1.1 Total greenhouse gas emissions from 1970 to 2010 from industrial processes and fossil fuel consumption. The accelerated rate in the past 40 years is demonstrated by this figure. From IPCC (2015).

Figure 2.1.2 Globally averaged air temperature and sea level rise rate. The accelerated rates of land and ocean surface temperature increase and the correlating sea level rise rate increase since the 1950's is visible. From IPCC (2015).

2.2 Local Sea Level Rise Trends

Recent evidence and studies suggest that the dynamic changes in the ice flow of the Antarctic and Greenland ice sheets could lead to a sea level rise of 5.0 meters or more by year 2100. It is probable that sea level could rise in more than 95% of the global oceans and 70% of the coastal areas could be up to 20% higher than the global mean (IPCC, 2015). This is a threat that could lead to drastic changes to the surrounding coastline areas of the Chesapeake Bay. The most debilitating threats driven by a rising sea level include flooding and permanent inundation. A rising water table factors into flooding rates and would increase the already frequent flooding (Figure 2.2.1). Increased erosion (Figure 2.2.2) facilitated by more frequent and severe storm surges would further increase the frequency and magnitude of flooding occurrence (Glick et al., 2008). In addition, SLR could cause saltwater intrusion into the groundwater and surface water. When the land becomes flooded from storm surges, saltwater can infiltrate into the freshwater lense from the surface and cause localized saltification. (Glick et al., 2008).

Rising sea levels could cause an inland migration of the freshwater and saltwater mixing zone because the rising sea water level leads to more saline water heads at the ocean boundary (Werner and Simmons, 2009). Ground topography and groundwater flux are two significant factors in determining the susceptibility to saltwater intrusion. Groundwater flux is determined by the hydraulic conductivity of the aquifer and other hydrogeologic variables. A rise in the sea level could reduce the hydraulic gradient of the freshwater aquifer, which would cause inland movement of the freshwater/sea water interface, and this causes saltwater intrusion (Klassen and Allen, 2017). The rate of the inland movement is dependent on the rate of SLR, which shows to be accelerating (IPCC, 2015, Klassen and Allen, 2017). Several hydrogeological studies have been done in the Gulf Islands that analyze aquifer hydraulic properties and responses to climate, SLR, and over-pumping. SLR was integrated into floodplain maps for each island using projected SLR data for year 2100 and estimated storm surge levels. This data was incorporated with pumping well density to identify which areas were the most vulnerable to salt water intrusion (Klassen and Allen, 2017). Additionally, Dr. Whittecar and Chris Johnson from the Department of Geological Sciences at Old Dominion University did a hydrological study of FLSP in 1990 (DCR, 2000). This study identified that the water table surface in the Cape Henry area forms into a broad asymmetric dome that is located in the southern area of Fort Story and it borders FLSP. The groundwater flow spreads from this elongated area towards the shoreline. Due to its location, a large amount of groundwater flows into the northern part of FLSP from the wetlands near the southern border of Fort Story. Based on Whittecar's analysis, the location of surrounding neighborhood wells, and the groundwater aquifer, sea level rise, heavy pumpage from ponds and future wells in southern areas of Fort Story would be what poses threats to groundwater levels and composition at FLSP (DCR, 2000).

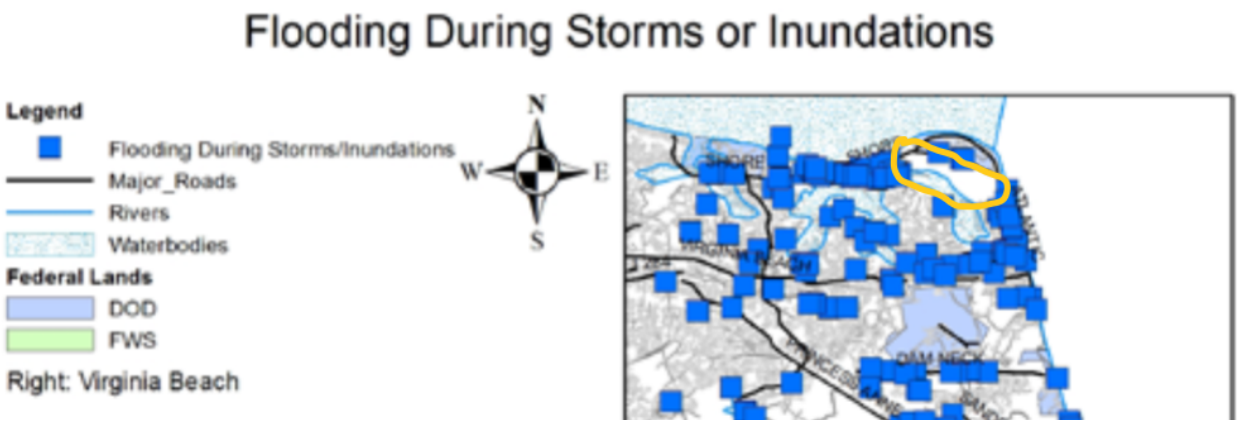


Figure 2.2.1 Floods during storms or inundations. The area circled in golden yellow is First Landing State Park. The blue squares indicate areas of flooding. FLSP is surrounded by currently affected areas. From Institute for Environmental Education (2011).

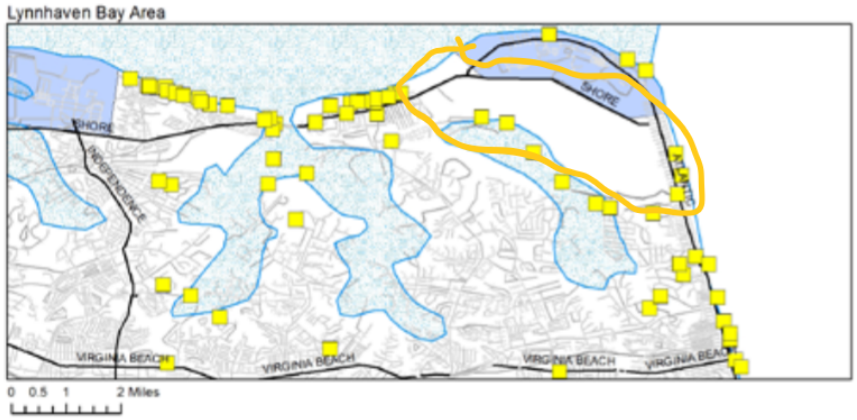


Figure 2.2.2 Areas impacted by erosion. The yellow squares on the map indicate areas impacted by erosion. The area circled in golden yellow is FLSP. There are areas in the southern part of the park, which include polyhaline and mesohaline marsh, affected by erosion. From Institute for Environmental Education (2011).

3. Vulnerabilities of FLSP to Sea Level Rise

3.1 Flora, Fauna and Natural Communities of FLSP

Hundreds of species of invertebrates, mammals, birds, and fish are threatened by the impacts of sea level rise and habitat loss in the low-lying coastline area of FLSP. FLSP is part of a habitat system that supports bird populations such as the osprey, snowy egret, great blue heron, various species of tern, mammal and reptile populations such as the cotton mouse, various species of bats, eastern ribbon snake and the chicken turtle (DCR, 2000, Glick, 2008). The species that occur in the various habitats are adapted to a certain level of salinity fluctuations, and an increase in the salinity could lead to a decrease in species composition and an increase in fragmentation of the brackish and freshwater marshes and swamps. Though there is a level of accretion that helps the dune, marsh, and forest habitats of this area to counteract changing water levels by increasing elevation or migrating inland with deposition of sediments, the sediment accretion may not be occurring at a linear rate to keep pace with the relative rate of SLR (Glick et al., 2008). Changes in the species extent and composition in the habitats can have far-reaching effects on the food-web of the Chesapeake Bay area (Glick, 2008). As stated previously, FLSP consists of 14 natural communities (see Figure 1.2). Of those communities, eight are rare in Virginia and at least two are globally rare. The rare maritime swamp ecosystem in FLSP occurs in several interdune swales about 1.0 to 1.5 km from the ocean, near the visitor's center. The bald cypress type maritime swamp forest is state and globally rare. This community type is currently in excellent condition but is vulnerable to the effects of increased storm surges, dune changes, and salt spray, which are expected to be exacerbated as sea level rises. The maritime upland forest ecosystem is the most abundant at FLSP, covering about 1,384 acres with a varying composition of pine trees, live oak, deciduous oaks, loblolly pine, and other plant species as the distance from the shore increases. The community type is identified as state and globally rare by the Virginia Natural Heritage Program due to its restricted ranges. The non-riverine swamps occur adjacent to the maritime upland forests and occur in about 1,066 acres of the park. They are considered globally uncommon to rare (DCR, 2010; Molleen, 2018).

The tidal mesohaline and polyhaline marshes occur at the southern part of the park bordering Broad bay and are irregularly or regularly flooded (Figure 3.1.1). Polyhaline marshes tend to consist of a salinity ranging from 18.0 to 30.0 ppt. Mesohaline marshes have salinities between 5.0 to 18.0 ppt. The vegetation structure and composition are affected by the duration and frequency of inundation, and the salinity. They were previously degraded due to mosquito ditching that occurred before the 1970's. This city initiative was discontinued in the 1970's. In addition, increasing sea level is already posing a threat for this community type as the inundation and salinity period is expected to continue to increase and drown out certain marsh areas and change the elevation of others. There has been evidence of the marshes encroaching on wooded upland forest ecosystems. This is demonstrated by the occurrence of snags of loblolly pines on many marsh areas (DCR, 2010, Molleen, 2018).

The interdune freshwater swale/pond community type occurs near sea level between dunes and the groundwater stands at or above the soil surface for enough of the year that a peat mat forms. This ecosystem can be found north of the visitor's center. The freshwater ponds are important for supporting a high diversity of rare species that occur throughout the park. This includes the rare carpenter frog that was originally believed to only occur in the cypress pools. Being found to occur in the ponds as well indicates potential population growth. A study done in 1997 concerning fish species composition of the cypress swamps resulted in cataloging 10 freshwater fish species (DCR, 2000). These included the mud sunfish, mudminnows, bowfin, perch, and pickerel. The interdune ponds are also preferred habitat for freshwater turtles and the rare chicken turtle, which is an endangered species of FLSP (DCR, 2010; Molleen, 2018). Freshwater turtles can adapt physiologically and behaviorally to varying levels of salinity and can live in brackish and marine environments for varying periods of time. However, most literature and observations do not indicate long-term salinity tolerance amongst freshwater turtle species (Agha et al., 2018). Sea level rise could potentially cause prolonged inundation and salinity changes to these delicate freshwater ecosystems. This could cause a rippling effect in the ecosystem as this community type

supports a high diversity of plant and animal species. It serves as breeding areas for amphibian populations, promotes growth of plant seedlings, provides nesting areas for birds and habitat for reptiles (DCR, 2010; Molleen, 2018).

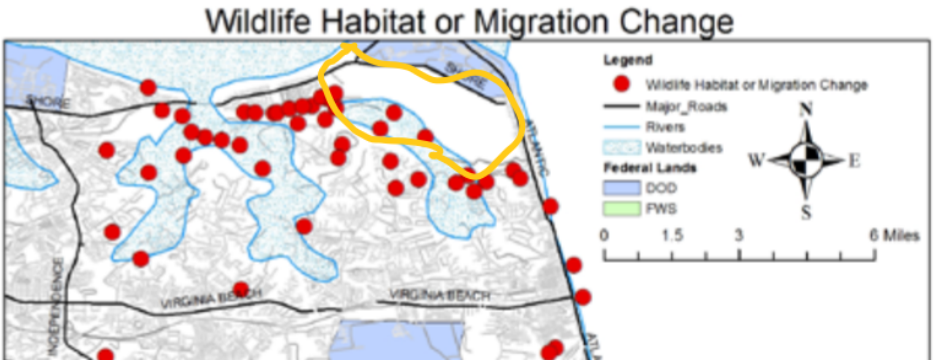


Figure 3.1.1 This map indicates areas of wildlife habitat change or migration change as red circles. The golden yellow line indicates FLSP. Represented are areas in the southern portion of the park in the tidal mesohaline/polyhaline wetlands that have experienced these changes. From Institute for Environmental Education (2011).

3.2 Recreational and Economic Activity

FLSP supports a system that is important to the cultural, recreational, and economic state of the Tidewater region. Visitors to Virginia State Parks promote beneficial economic activity throughout the state. These visitors spent about $226.1 million in the Virginia Commonwealth in 2017. About $104 million of this was spent by out-of-state visitors. The analysis done in 2017 by Vincent Magnini at Virginia Tech further evaluated the economic impact of the Virginia State Park system and the level of contribution from the individual parks. The economic impact is a measure of the amount of "fresh money" in the state's economic system that would not have been there if the park system was absent. (Magnini, 2018). The economic impact of the park system in 2017 was about $239.4 million. FLSP contributed $23.5 million of the economic impact. Compared to the other parks of Virginia, FLSP is one of the top revenue providers. Also, the nature of the parks encourages locals to spend within the

commonwealth for the recreational activities they seek. This helps to sustain state economy. FLSP specifically provides enticing recreational activities such as hiking, boating, biking, fishing, camping, beach access, and educational programs. Not only does the park provide economic benefits, but it also provides societal benefits such as stress-reduction, relaxation, and other health benefits (Magnini, 2018).

Flooding and inundation pose a great risk to the recreational and economic function of First Landing state park. Though currently inundation is not causing a major activity loss, there has been increased occurrences of flooding in developed areas of the park and campgrounds. There is also erosion of wetlands bordering Broad Bay which could potentially impact Long Creek and Osprey hiking trails as sea level continues to increase (Institute for Environmental Education, 2011). Studies that analyze the storm surge occurrences of major storms in relation to SLR, by, for example, comparing the major storm of 1933 to hurricane Isabel in 2003 (Hardaway, 2005), have shown that the positive difference of current sea level and past sea level correlates to the significant increase in the storm surge level. This directly affects the changes of the shoreline. With one of FLSP's popular attractions being the beach access of the Bay, major damage to the shoreline due to storm surges and erosion could have impacts on the number of visitors and thus revenue (Hardaway, 2005).

4. Foresight: Possible Futures of FLSP

Projecting future sea level rise and the potential impacts is a challenge amongst scientists due to the level of uncertainty with anthropogenic and climatic variables. However, developing modelling and empirical methods have aided in creating a spectrum of possible outcomes and scenarios for future sea level. Climatic forced sea level and temperature changes are frequently correlated (Cronin, 2013). In analyzing how past patterns of climate and sea level changes associate with sedimentation and vegetation composition in the Chesapeake Bay area in the past 8,000 years, future outcomes can be more effectively developed (Cronin, 2013).

To develop low to high risk scenarios for sea level rise in the FLSP area, information was utilized from the 2014 synthesis report of the Intergovernmental Panel on Climate Change (IPCC), studies of the Union of Concerned Scientists (UCS), studies of the US Geological Survey (USGS), and findings of scientists Robert Deconto and David Pollard. Carnegie Mellon University's CREATE Lab's EarthTime project that uses large global data sets to create visual environmental changes is also incorporated. A local sea level rise of 0.55 m to 1.0 m by year 2100 would be considered a low-risk scenario for FLSP. This SLR rate would allow for more time to support the habitats' resilience and ability to migrate. A local sea level rise of more than 2.1 m would be a high-risk scenario for FLSP because the rate of sediment accretion and habitat migration would likely not keep pace with the rate of SLR (Glick et al., 2008, Caldas et al., 2017).

Based on scenarios presented in IPCC (2015), global mean sea level rise could be between 0.26 m to 0.96 m by year 2100, if accelerated ice melt is not considered (Figure 4.1). Assuming significant decrease in carbon emissions and minimal influence from ice sheet loss, the Union of Concerned Scientists predicted a possible global mean SLR of 0.5 m above the 1992 level with no more than a 2.0 ^{o}C temperature increase (IPCC, 2015; Caldas et al, 2017). FLSP could experience a local SLR that is 20% higher than the global mean. In this scenario, FLSP could have a SLR of 0.6 m to 0.9 m (Glick et al., 2008). Areas of the beach at FLSP and areas of the southern portion of the park bordering Broad Bay would be frequently flooded, eroded, and/or permanently inundated (Figure 4.2). As discussed in Section 3, this would impact visitor access to the beach, a popular attraction at the park, the mesohaline and polyhaline marshes in the southern portions of the park would be inundated, and the southern trails could be damaged or flooded. This scenario would allow for an extended time frame for habitat management planning and execution, and possible habitat protection and migration. The increased time to protect and transition wetland areas and woodland areas would help sustain the flora and fauna species of the area.

In an intermediate risk scenario, the global sea level could rise between 1.2 m to 2.1 m. Assuming that carbon emissions continue at a positive trend until about year

2050 and then slowly decline and there is moderate ice sheet loss, the global sea level could rise by at least 1.2 m (Caldas et al., 2017). This would mean a local SLR of at least 1.5 m for FLSP (Glick et al., 2008). This would be a detrimental scenario for FLSP (Figure 4.3). With proper management, the beach and dune ecosystem communities could migrate inland to survive the rising sea level and the brackish marsh in the southern portions of the park could migrate to upland forest communities, and in turn the upland forest communities could migrate inland as accretion allows. But without sufficient beach nourishment projects or sediment accretion patterns, the beach bordering the Chesapeake Bay could be severely damaged and the limited area of the aquatic natural communities could be further degraded due to increased temporary and permanent inundation. The freshwater interdunal ponds would be at severe risk and the increase in high salinity patterns due to intruding saltwater would alter the varying ecosystems. The most southern trails would be inundated and the campgrounds on the beach side of the park would be inundated.

In a high risk scenario, the global sea level could rise at least 5.0 m. This would mean a local SLR of at least 6.0 m for FLSP (Glick et al., 2008). Assuming rising carbon emissions and rapid ice sheet loss, the Union of Concerned Scientists determined a possible global SLR of at least 2.0 m (Caldas et al., 2017). This would correlate to a local SLR of at least 2.4 m for FLSP (Glick et al., 2008). However, if carbon emissions continue and the Antarctic ice sheet melts at an unprecedented accelerated rate, this could cause a global SLR of at least 15.0 m by year 2500 and a local SLR of at least 18.0 m for FLSP (Glick et al., 2008). Data also suggests there is a contribution of the Greenland ice sheet loss to SLR (Dennis and Mooney, 2016). This scenario is supported by modeling of coupled ice sheet and climate dynamics, including atmosphere warming and hydrofracturing of restraining ice sheets, which indicates that the Antarctic ice sheet could potentially lead to over a 5.0 m global SLR by year 2100 and over a 15.0 m global SLR by year 2500 (Deconto and Pollard, 2016). With a global sea level rise of 5.0 m or higher and local SLR of 6.0 m or higher, FLSP as it is now could be completely inundated or at least 90% inundated and the remaining area would be frequently

flooded (Figure 4.4). Without drastic changes or efforts to protect and facilitate migration of the rare natural communities that FLSP encompasses, the rare and endangered species that occur there would be lost. The opportunity for recreation in the park's natural lands and beach would also be lost.

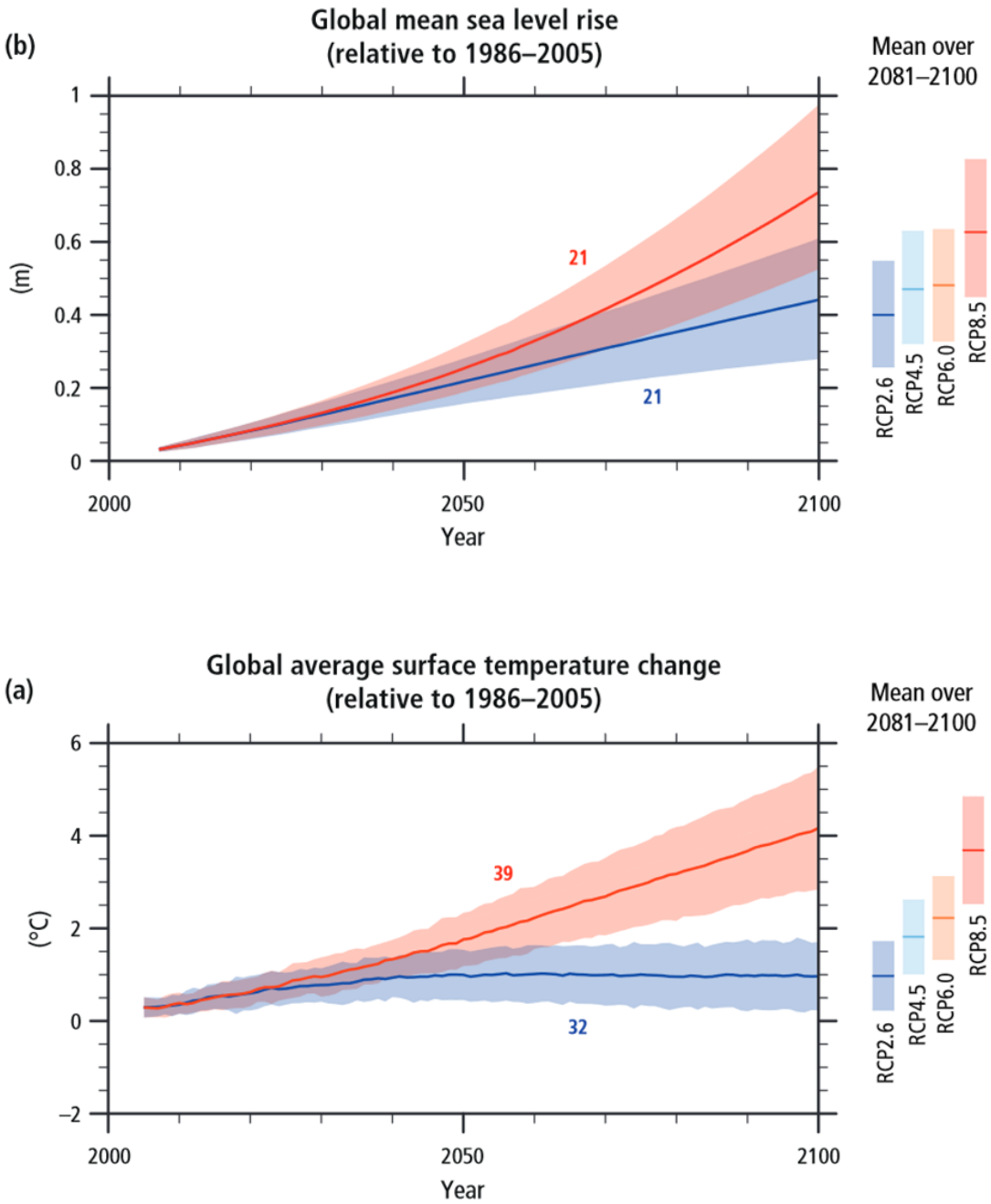


Figure 4.1 Global sea level rise and temperature increase in the 21st century. The top graph shows plausible global sea level rise trajectories up to year 2100 depending on different emission scenarios. The bottom graph shows the same for global average temperature change. From IPCC (2015).

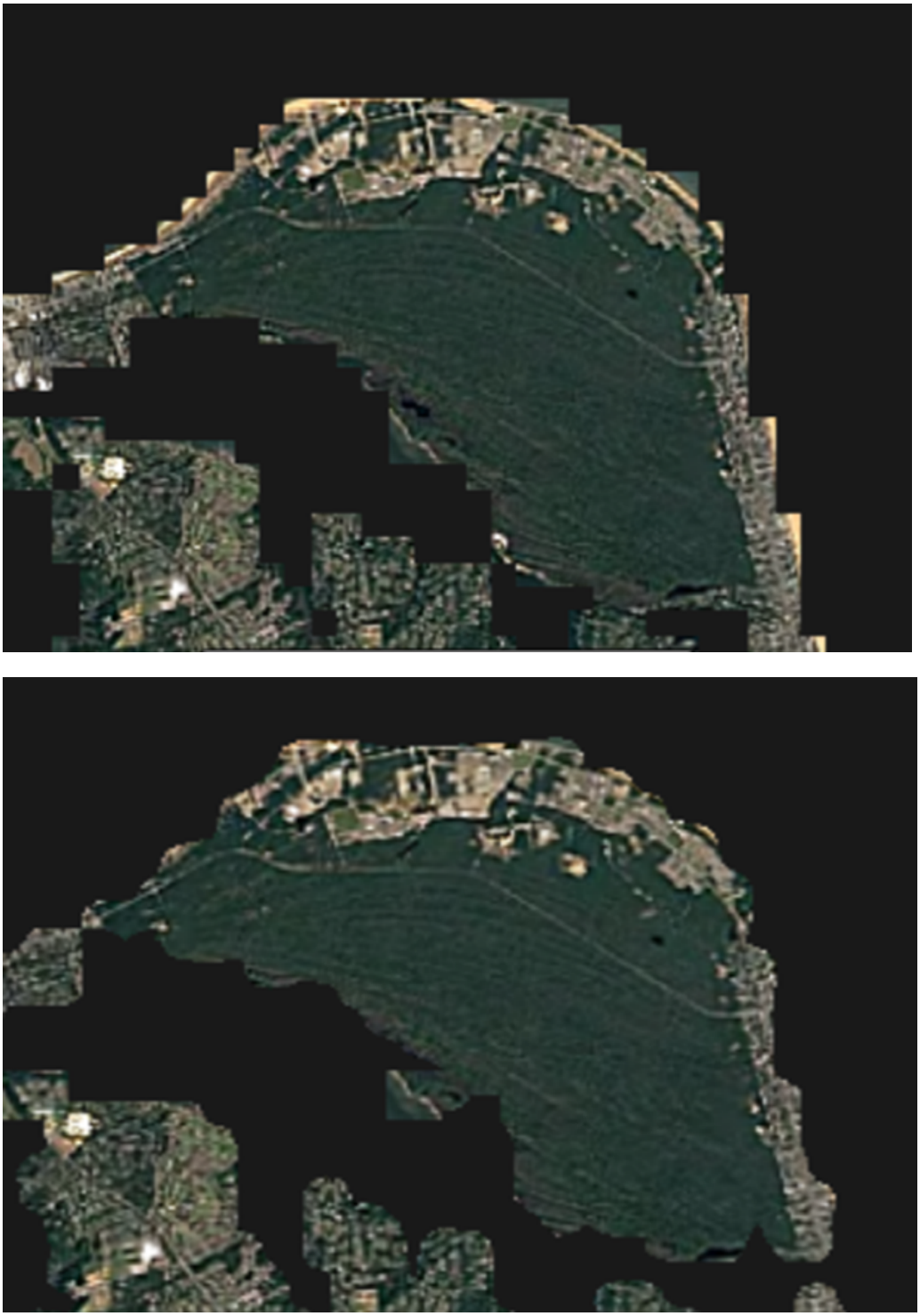


Figure 4.2 Impact of a low-risk SLR on FLSP. The top map shows the approximate current map of FLSP as sourced from NASA's satellite imagery. The bottom map shows a possible outcome of a global SLR of 0.7 m and local SLR of 0.9 m for FLSP. The black is open water (Earthtime, 2018, Glick et al., 2008).

Figure 4.3 Impact of a medium-risk SLR on FLSP. This map shows an outcome of a global SLR of 2.1 m and local SLR of 2.6 m for FLSP. The black area is open water (Earthtime, 2018, Glick et al., 2008).

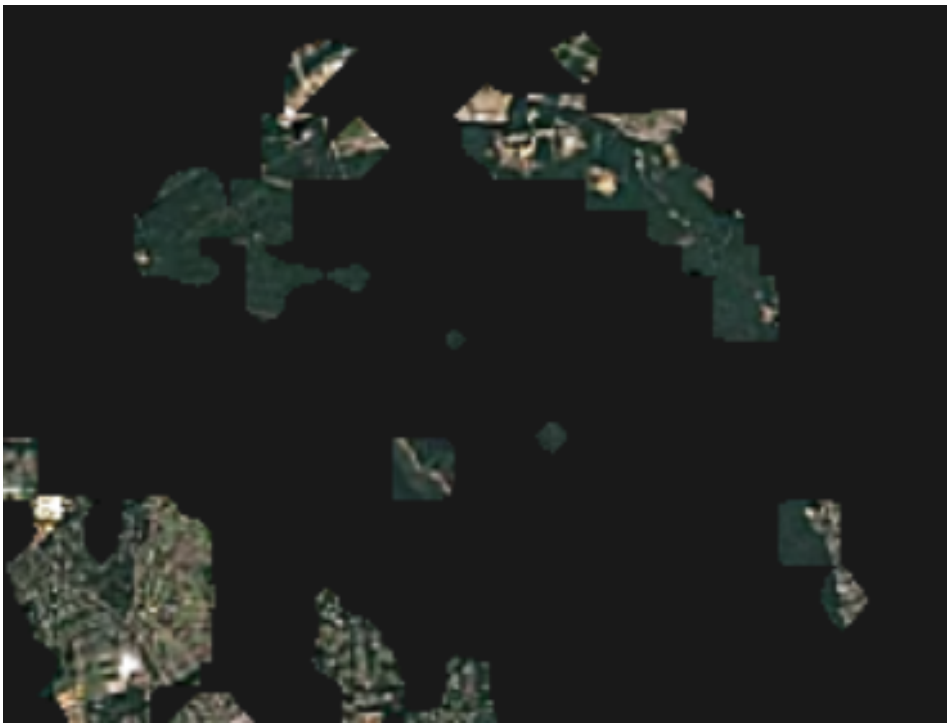


Figure 4.4 Impact of a high-risk sea level rise on FLSP. This map shows an outcome of a 4.7 m global SLR and 5.7 m local SLR for FLSP. Majority of the park is inundated and the remaining area at high risk of flooding. The black area is open water (Earthtime, 2018, Glick et al., 2008).

5. Decision-Making and Stakeholders

The FLSP operates under the resource management plan that is developed and revised about every 20 years under the direction of the State Department of Conservation and Recreation (DCR). It is reviewed every 5 years to follow-up on completed projects and reevaluate the progress and priority of others. This plan guides management actions and planning. DCR is the lead conservation agency of the Commonwealth of Virginia. In addition, FLSP follows guidelines placed by the federal Department of Interior's National Natural Landmark program, as approximately 1,500 acres of the park are on the National Registry of Natural Landmarks. The purpose of this program is to preserve natural areas that are of unique ecological and historic significance to promote public appreciation of natural history and conserve the nation's

natural heritage. Planning falls under direction of the Virginia Natural Areas Preserve Act (DCR,2000).

In addition, FLSP operates under agreements of the City of Virginia Beach, which directs management of specific areas of the park. A newer agreement with the Virginia Marine Science Museum involves operating a wet lab in the Chesapeake Bay center. This public educational facility opened to the public in the summer season of 2018. Local associations like the Cape Henry Shore's Civic Association also works with FLSP staff on projects involving landscaping and the planting of native species. Management practices must adhere to guidelines of the Chesapeake Preservation Act. The Virginia government also requires the submission of an environmental impact report to the Department of Environmental Quality for any major projects (DCR, 2000).

The state and local government and agencies are major players in operating and preserving the FLSP. Management decisions and policies are developed, approved, and executed under the direction of these groups. The role of the governor and the local population in planning and execution of projects at the park is distinctively important. The park serves as a major recreational and natural landmark to the general public, and this drives public interest in park operations. A survey conducted at a Virginia Beach listening session in 2011 showed that a large portion of the participants consider SLR an important issue in Virginia Beach and believe that the local government needs to give priority to addressing the issue (Figure 5.1; Institute for Environmental Education, 2011). To facilitate further research and outreach educational programs regarding sea level rise, climate change, and the impacts on the park, including erosion and inundation risks, the local and state community involvement and collaboration with federal agencies is necessary. Continued efforts in public education and involvement will push progress for mitigation projects (Stein et al., 2018).

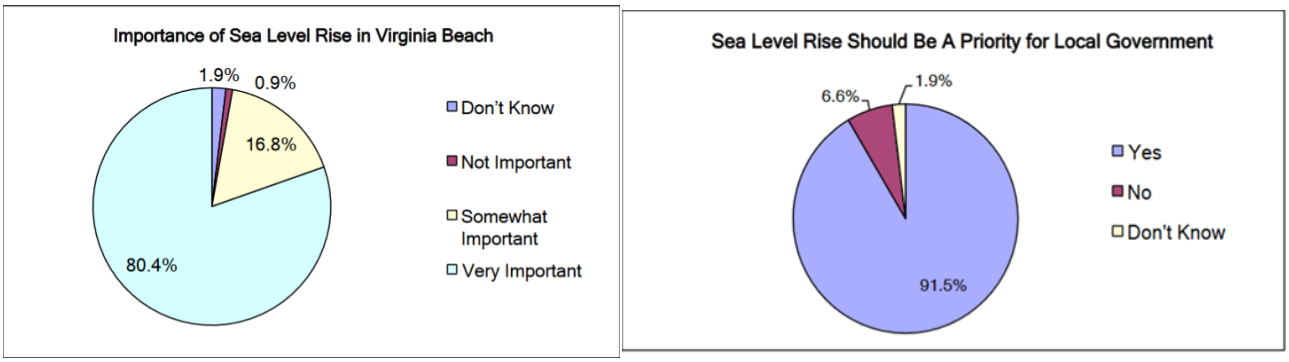


Figure 5.1 Public opinion about the relevance of sea level rise in Virginia Beach. The two graphs represent the opinion of individuals that participated in the Virginia Beach listening session in 2011. Left: A large majority of the individuals considers the issue of SLR to be very important. Right: A majority of the individuals responded that SLR needs to be a priority for local government. From Institute for Environmental Education (2011).

6. Options

6.1 Current Management Practices

Within the current management plan at FLSP there are management objectives in place to maintain a healthy ecosystem within the park natural communities and promote a resilient component and structure. The FLSP staff also identify, monitor, and control invasive species that could cause damage to the system. This includes the non-native invasive phragmite that is resilient in an environment that has accelerated salinity and water level changes and spreads readily. In addition, procedures also aim to protect and preserve rare, threatened, and endangered species of FLSP.

6.2 Additional Studies in Topographical Changes

To better support planning for impacts of sea level rise induced erosion, storm surge increase, and inundation, additional studies that map changes in shoreline, dune, and wetland areas need to be executed. A study was done in the spring of 2007 at FLSP that used techniques to produce resultant topographic digital data of a dune complex on the shoreline bordering the Chesapeake Bay (Mcleod et al., 2007). This resultant data could be used to quantify and catalog changes in the shoreline, foredunes, dune ridges,

and pioneer forest. The methods using global positioning system receivers and GIS inspections were designed to be simply replicated. By comparing the changes over time in the shoreline with the dune elevation changes one could develop an approximate sedimentation or accretion rate, as well as a dune growth rate (Figure 6.2.1). This can be used to create models that demonstrate possible outcomes for topographical changes and coastline changes in the future as it relates to sea level changes, currents, and other climate factors (Figure 6.2.2; Mcleod et al., 2007). This data could help dictate if and where facilitated sediment renourishment and flora restoration may be needed to prolong protection of various terrestrial and aquatic communities of FLSP.

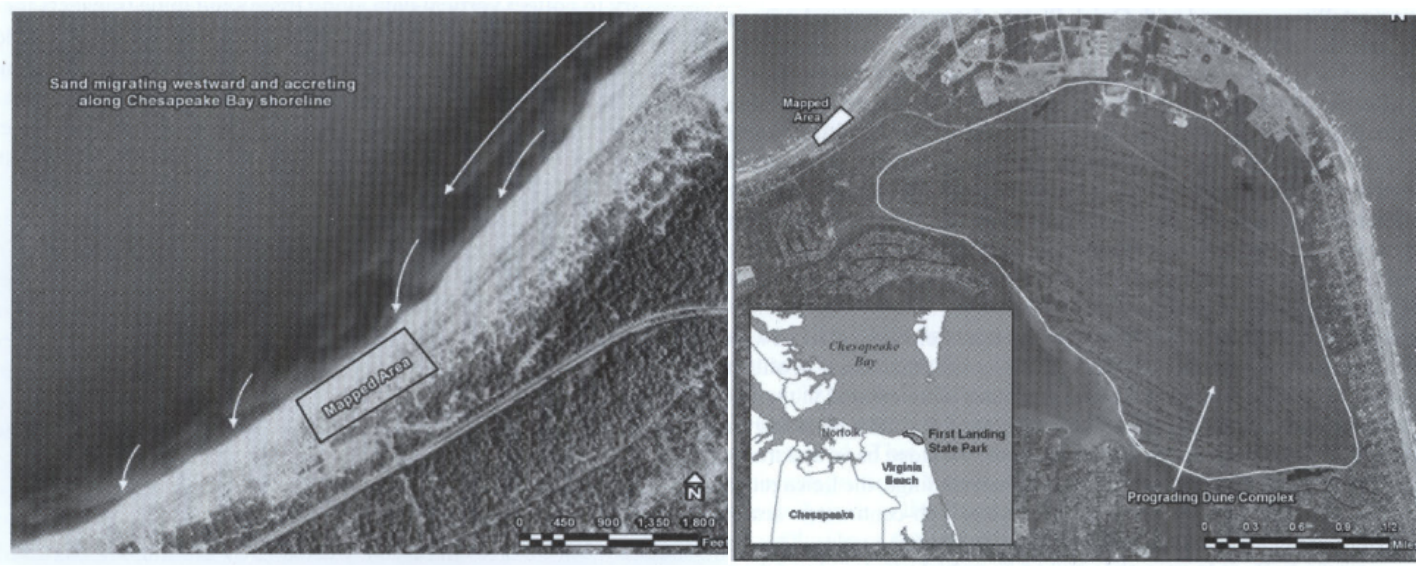


Figure 6.2.1 Left: longshore drift and accretion around the mapped area for the study. Right: Area of study at FLSP. From Mcleod et al. (2007).

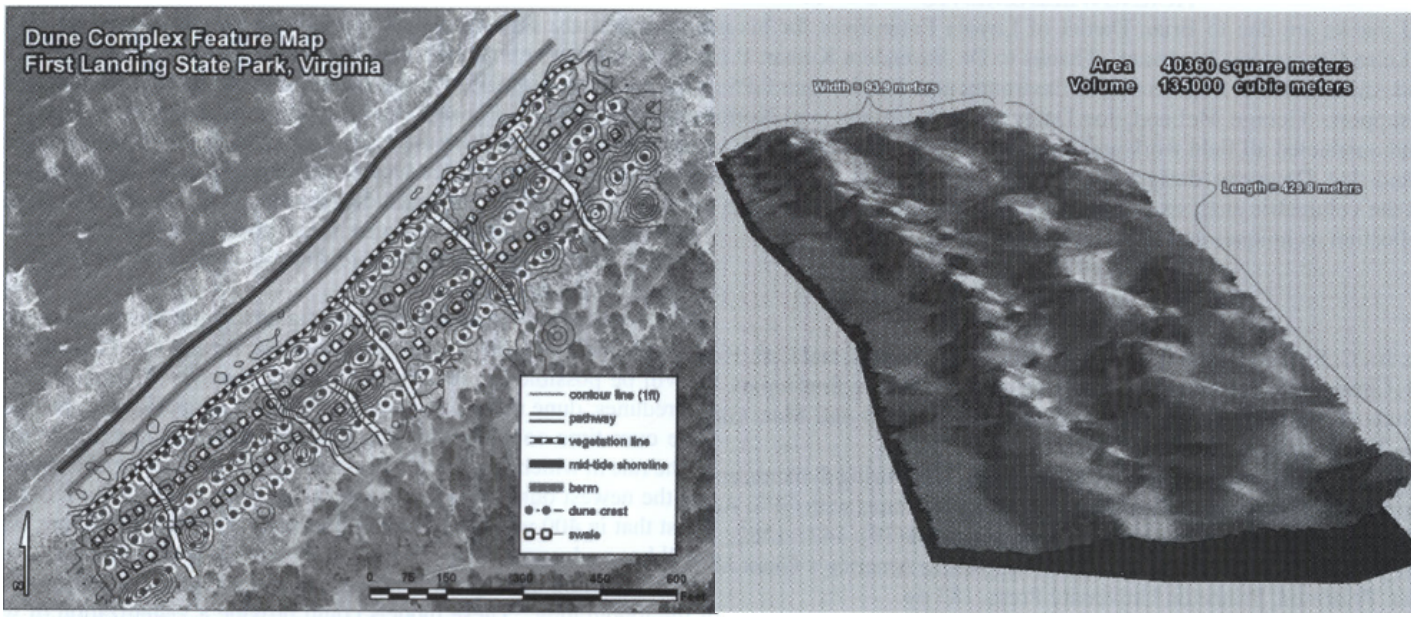


Figure 6.2.2 Left: Contour and feature map using aerial imagery of the area of study. Right: Preliminary 3-D elevation model of the mapped dune area. From McCleod et al. (2007).

6.3 Tidal Marsh Restoration and Preservation

The mesohaline and polyhaline marshes located in the western and southern areas of the park are highly threatened by SLR. Prolonged saltwater intrusion and inundation stress these wetland habitats by potentially decreasing flora composition and decreasing land area for this habitat. Invasive plant species further pressure this community. Change in the salinity and decrease in flora composition could in turn affect the bird, fish, and other fauna species that occur in this community and other interconnecting flows with other natural communities and ecological components. To protect this habitat, further promotion of native plant species, such as saltmeadow cordgrass and saltmarsh fleabane, may be needed. Continue to closely monitor invasive species like phragmite common reed and do manual removal if necessary. Planting of native species could be done if population numbers decrease to an undesirable number. As evidence of marsh migration has been seen with snags of loblolly pine in some of the marshes, it would be beneficial to facilitate transition of ideal higher elevation areas to tidal marshes. This could be done by monitoring species and elevation levels, and plant

ideal marsh flora species as needed in desirable areas. This would help protect the species composition of the tidal marshes. This would in turn support the local environment's resilience and ability to migrate (DCR, 2000).

6.3 Land Easement and Corridor Development

Another option would involve slow land acquisition or easement in the areas, west, southwest, and south of the park to allow for further opportunity to create areas for the marsh, wetland ecosystems and upland forest ecosystems to migrate and to protect the native species of FLSP in the long-term. If areas along the southern and western borders of Broad Bay, which borders the southern and south western edge of the park, were slowly transitioned to available open land via people retreating more inland, more area for habitat migration and wildlife corridors could be developed. Management intervention may be needed to assist in the migration and support of flora and various native cordgrass species populations to these areas (Titus, 1988). The ability to gain the support of the people would pose a challenge in several cases, but public survey assessments show promising results in public support in action taken to address sea level rise impacts (see Figure 5.1; Institute for Environmental Education, 2011).

6.4 Citizen Science Program Development

FLSP currently develops and executes educational programs and exhibits that run primarily during the spring and summer months. There are some programs that run during the fall and winter months. The programs prove to be popular among the local community and out-of-state visitors and this promotes frequent and new visitors to the park and the programs. This would be an ideal opportunity to develop a program to educate the public on the issue of sea level rise and how it could impact the park and how it could impact them. Facilitating increased interest and involvement in addressing the issue of SLR and the environmental impacts would promote potential observational data collection that would aid in management decisions. It could also increase public support and involvement in projects that help to preserve the habitat, fauna, and recreational opportunities of FLSP.

7. Recommendations

Based on the developed scenarios of sea level rise and the potential impacts to FLSP, research on the topographical changes, shoreline changes, and dune complex changes of FLSP need to be expanded to inform actions to best preserve the habitat composition of FLSP. The projects should be based on the methodology developed in the high resolution dune complex mapping studies discussed in Section **6.2**. The gathered data on how the shoreline, dunes, and marsh wetlands of the area fluctuate with changing currents, sea level, erosion, and other climatic factors combined with existing information would assist in evaluating future trends of the habitat and deciding how to pursue current wetland, dune, and upland forest management decisions (McCleod et al., 2007). This should be additionally incorporated into addressing the flora populations in the mesohaline and polyhaline tidal marshes and most effectively establish the necessary salt cordgrasses and other beneficial native plants. This would facilitate a healthy system to support the birds, amphibians, and reptiles that thrive in this area, such as blue crab, turns, gulls, osprey, egrets. Raposa et al. (2017) provide additional insights into monitoring the restoration of the wetlands based on findings across different areas of the United States. Resource managers should identify the critical factors that control marsh stability that could be managed to develop successful marsh-restoration plans and large-scale restoration efforts coupled with an improved understanding of the effects of annual burning, nutrient enrichment, and sea-level rise. Knowledge of these factors is necessary to control the trends of wetland degradation and damage to the dune forest the marshes are invading into (Cronin, 2013).

In addition, FLSP would benefit from developing an educational program that educates the public about sea level rise, SLR trends, and what the potential impacts on the park and surrounding coastal area could be. This program could drive a strong interest in individuals to become more involved in data collection and conservation efforts for FLSP and other state parks. Aspects of current programs could be developed to include some educational material or activities that teach the public about SLR. For

example, the Bay Lab in the visitor's center could include an interactive component for showing individuals past and future trends of sea level rise. In addition, a volunteer-based research program could be developed to aid in data collection for dune changes, shoreline changes, and topographical changes in the park. A mobile-app based research project developed for FLSP would also aid in gathering beneficial information. It could be made specific for FLSP or work with an existing app-based project. It is an inexpensive method that would also promote citizen participation in data collection and scientific research, and further conservation efforts (Klemick, 2018).

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