Sea Level Rise Impacts and Barrier Island Response in Back Bay National Wildlife Refuge

Photo by Nikolai Karlov

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Table of Contents

Executive Summary

In the face of rapid, accelerating global, regional, and local scale sea level rise under a changing climatic and hydrologic system and all the hazards involved; I will be addressing the following questions to help guide managers and stakeholders of Back Bay National Wildlife Refuge (NWR) in the decision making process under different scenarios:

- What are the thresholds of the barrier island system in Back Bay with regards to ocean-bay breaching events?
- What are possible locations of such events, how are they vulnerable?
- Is a breach scenario more likely to occur in response to sea level rise and storm surge events or should managers expect a slow, gradual rise in water levels from the Oregon Inlet to the south?
- Which is a better scenario, ecologically, for Back Bay's managed ecosystems and species: a fast ocean breach or slow sea level rise?
- Under a breach scenario, what are the most likely impacts considering the vulnerabilities associated with the dune system, the nature of barrier islands, and the fragile freshwater ecosystem and species it protects behind it, specifically submerged aquatic vegetation (SAV) and the American Wigeon?
- To what extent should the refuge and other stakeholders be involved in combating or aiding the projected changes?

The uncertainty that comes with sea level rise and climate change make it nearly impossible to accurately predict a scenario will or will not happen. Therefore, when assessing various scenarios, it is important to recognize that projections do not count as predictions. Updated models are projecting an increase in global mean sea level (GMSL) of up to 2.5 m by 2100 as the worst case scenario (Sweet et Al., 2017). To maintain proper foresight, we must consider a range of scenarios, including the worst case, when dealing with dynamic projections of this sort. With the goal of Back Bay National Wildlife Refuge being to protect and preserve on a longterm temporal scale, the worst case scenario should be used to determine how stakeholders prepare for and manage the refuge system. This report does not attempt to make decisions for any involved party, but acts as a reference to be used alongside other sources – possibly to aid in the creation of the next refuge conservation management plan.

The nature of barrier islands must be understood to assess the vulnerabilities present. Barrier islands have a high degree of natural variability in location – meaning they aren't fixed to one spot by any hard structure underneath. They are essentially very large sandbars that are prone to shifting and migration under

certain natural stresses such as shifting currents, sea level rise, and extreme storms. Under natural circumstances, barrier islands will respond to these events by moving seaward or landward over time but do not often become totally inundated. In many cases, inlets naturally open and close as different processes occur. I have identified historical inlets around Back Bay as well as previous sites of breaching events into the bay. To determine a threshold for barrier island breaches, I took the water level data from the tide gauge of the last time a breach occurred in Back Bay, then imposed current sea level rise scenarios upon it to show the current threshold for a breach to happen in vulnerable locations. I used NOAA's Sewells Point tide gauge to assess water level trends and thresholds in the area. After breach locations and thresholds are identified, I then addressed the impacts that this could have on the ecosystem as opposed to a slow rise in sea level from the south. Using this information, refuge managers will be able to decide whether fighting a breach with various techniques is more beneficial than allowing/promoting a breach event.

After hazards, vulnerabilities and foresight were considered; it is apparent that under multiple different sea level rise and climate change scenarios, the barrier island of Back Bay National Wildlife Refuge is subject to ocean breaching in the near future and the threat is becoming more eminent as sea levels rise and the chances for extreme weather impacts increase. Having avoided a major storm surge event for the past 50 years, the probability of 1 in a 100 year storm which would lead to a breach (allowing for rapid sea level rise and salt water intrusion) is much higher than is a gradual sea level rise and salt water intrusion from the south. As the Atlantic Ocean warms, potential for stronger tropical hurricances to occur farther north increases, creating conditions that could severly impact the barrier island. Certain points on the barrier island dune system are topographically and morphologically more vulnerable to a breach by storm surge or extreme high tide. As seen in Figure 3. at least two potential breach locations have been identified under certain constraints as vulnerable surrounding Back Bay NWR: Little Island Park to the north and Bodie Island to the south.

There are a few options for adapting to and mitigating the impacts of sea level rise around Back Bay. One option, a preemptive measure, is to reinforce the dunes and beaches of Back Bay through intensive renourishment projects and defense structures. Another option, a reactionary one, would be to fill in any inlet that is created and fight to keep the seas from entering the bay as long as possible. Lastly, the refuge could consider a no action option; simply allowing nature to take its course and if a breach occurs, simply let it happen and adapt to the changes. With all of these options, there are important economic and ecological impacts that must be weighed and carefully considered. Ultimately, these will be relatively short term strategies for the refuge as SLR threatens to inundate the majority of the island by 2100.

1. Introduction

Back Bay NWR was first established June 6, 1938 in effort to preserve and protect the land from urban expansion in Virginia Beach as it is a critical part of the Atlantic Flyway for migratory birds to feed and rest. The refuge contains several habitats including beach, dunes, woodlands, fields, and emerging wetlands which all provide important ecosystem services for local flora and fauna (USFWS, 2016). In terms of fauna, the refuge gives sanctuary to thousands of migrating geese, ducks, and swans every fall and winter season. Additionally, essential habitat is provided for many threatened, endangered and recovering species such as the Loggerhead Sea Turtle, the Piping Plover, Brown Pelican and Bald Eagle. Included in the refuge is a thin strip of barrier island along the Atlantic, preventing Back Bay from being inundated with saltwater and creating a brackish zone which could harm the inhabitants. The closest inlet allowing salt water into the bay is Oregon Inlet in the Outer Banks of North Carolina, close to 70 miles south of Back Bay NWR. In the past, the barrier island has been breached as a result of major storms eroding the dunes through storm surges. These breaches allow for salt water intrusion into the bay and can lead to an alteration in salinity in the bay itself as well as the water table surrounding it. With Back Bay being a freshwater ecosystem, its inhabitants are naturally vulnerable to changes in salinity - however, the extent of vulnerability is specific to each species. Going into the future, an important part of conserving and protecting Back Bay NWR will be to understand the effects that current global changes will have on the morphology of the refuge. In particular, the impacts that sea level rise and extreme storms will have on the ecosystems must be studied in the area to understand where and under what circumstances ocean water might breach the barrier island, the severity of the potential breach, and what actions must be taken to help prevent or manage such an event should it happen.

In the last 2,000 years, the Earth has maintained a relatively stable sea level that has allowed for humanity to live within many coastal regions around the world (Sweet et Al., 2017). In the past few decades, however, science has unveiled strong evidence that suggests the state of the Earth's natural systems and environments is dramatically being altered as a result of natural processes becoming enhanced by a variety of human impacts. As energy inputs and withdrawals have become highly unbalanced over the last century, the planet's dynamic atmospheric, oceanic, and terrestrial systems have undergone drastic changes in both their chemical and physical properties. Global climate change is one of the most evident and well recorded changes to the Earth and is the driving force behind current long-term sea level rise (SLR) (Sweet et Al, 2017). Likely to have lasting affects for centuries, long-term global sea level rise (GSLR) is considered a guaranteed and highly hazardous threat to the coastal communities and ecosystems of the United States.

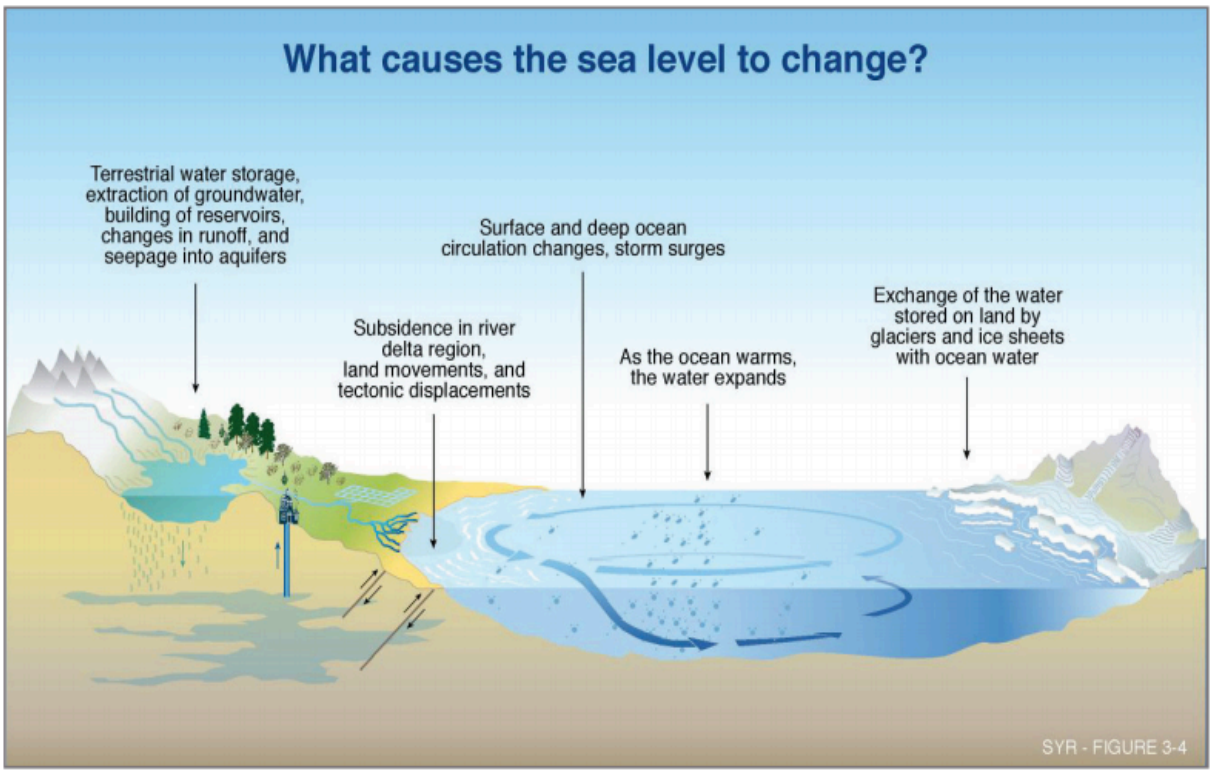

Figure 1. A graphic sourced presented by Parris et Al in 2012 representing the processes resulting in global sea level rise.

GSLR under global warming is caused by the two major processes of thermal expansion and glacial melting shown in Figure 1 (Parris et Al., 2012). Within the last century, global sea levels have risen on average 1.7 mm/year and in the past few decades this rate has been estimated to have increased to 3.2 mm/year with projections suggesting future rates will be even higher (Smallegan et Al., 2017). On a regional scale, sea level rise occurs as a combination of geophysical processes within the area. SLR in Hampton Roads is considered to be one of the fastest and most impactful in the United States with an average rate of 4.61 mm/year as seen in Figure 2 (NOAA, 2015). SLR in this area is influenced by natural and anthropogenic vertical land motion (VLM), thermal expansion, land ice melt/discharge, ocean current shifts, tides, storm surge, and wind waves over differing spatial and temporal scales with a range of potential magnitudes (Table 1) (Sweet et Al., 2017).

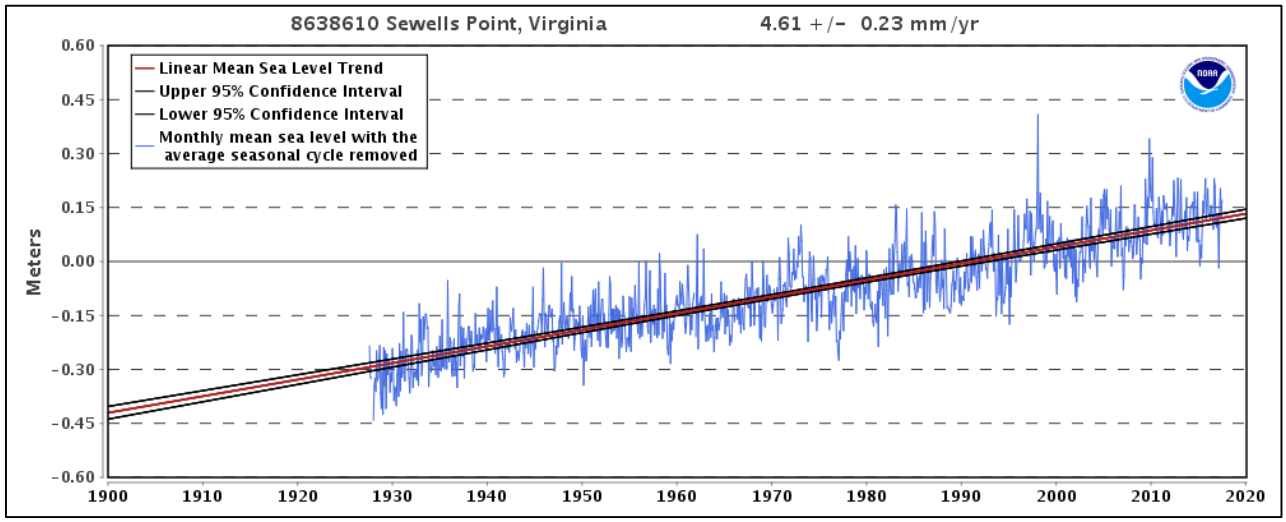

Figure 2. Tide level trends from 1927 to 2016 showing the increasing trend in mean sea level at Sewells Point, Virginia. Currently at 4.61 mm/year, this area has one of the fastest rising sea levels in America – largely due to land subsidence, though some scientists speculate shifting ocean currents may play a role (NOAA, 2016).

Physical Process	Spatial Scale			Temporal Scale	Potential Magnitude (yearly)
	Global	Regional	Local		
Wind Waves (e.g., dynamical effects, runup)			X	seconds to minutes	<10 m
Tsunami		X	X	minutes to hours	<10s of m
Storm Surge (e.g., tropical storms or nor'easters)		X	X	minutes to days	<15 m
Tides			X	hours	<15 m
Seasonal Cycles		X	X	months	<0.5 m
Ocean/Atmospheric Variability (e.g., ENSO response)		X	X	months to years	<0.5 m
Ocean Eddies, Planetary Waves		X	X	months to years	<0.5 m
Ocean Gyre and Over-turning Variability (e.g., PDO response)		X	X	years to decades	<0.5 m
Land Ice Melt/Discharge	X	X	X	years to centuries	millimeters to centimeters
Thermal Expansion	X	X	X	years to centuries	millimeters to centimeters
Vertical Land Motion		X	X	minutes to centuries	millimeters to centimeters

Table 1. Causes of sea level rise on various spatial and temporal scales with attributed potential magnitudes (Sweet et Al., 2017).

In order to understand the influence that this projected sea level rise will have on Back Bay NWR barrier islands, one must understand first the nature of barrier island systems. A significant characteristic of a barrier island is that it is prone to move landward or seaward via the process of overwash, often referred to as "roll-over" depending on the capacity of the sediment bank (Titus et Al,. 2009). As sea levels rise, a barrier island will be subject to erosion, storm surge, and breaching events which help to push the island landward and upwards under most circumstances. The back barrier system of estuaries and lagoons behind the dune is a critical part of this processes. When an overwash event or breach occurs, sediments are deposited on the backside of the island and held in place by the marshy substrate allowing the island to rise in elevation over time. The marsh then moves landward and the barrier island follows as this is repeated. In areas of anthropogenic development and management that block sediment movement by housing, sea walls, dikes or other barriers, these processes can be hindered and ultimately lead to the island being unable to migrate fast enough to keep up with sea level rise and eventually become submerged or highly segmented. The future of a low-elevation and narrow barrier island under sea level rise is therefore contingent upon its ability carry out these natural processes (Titus et Al., 2009). In line with this thought, thresholds exist for these barrier islands and when crossed they will be subject to barrier segmentation, barrier disintegration, or landward migration and rollover (Titus et Al., 2009). Back Bay NWR has been identified as vulnerable to exceeding these thresholds. Under the current 20th Century rate of sea level rise, Back Bay barrier island is currently subject to overwash, erosion, and island breaching before any additional sea level rise occurs as seen in Figure 3 (Titus et Al., 2009).

Understanding this information is valuable for refuge managers who are expected to make wise, well informed, sustainable choices that will have the most benefit economically and ecologically for the refuge. These options will be further explored in this report, however, there are deficiencies in research that may alter the viability of these options in the future so they must be considered with practical discernment.

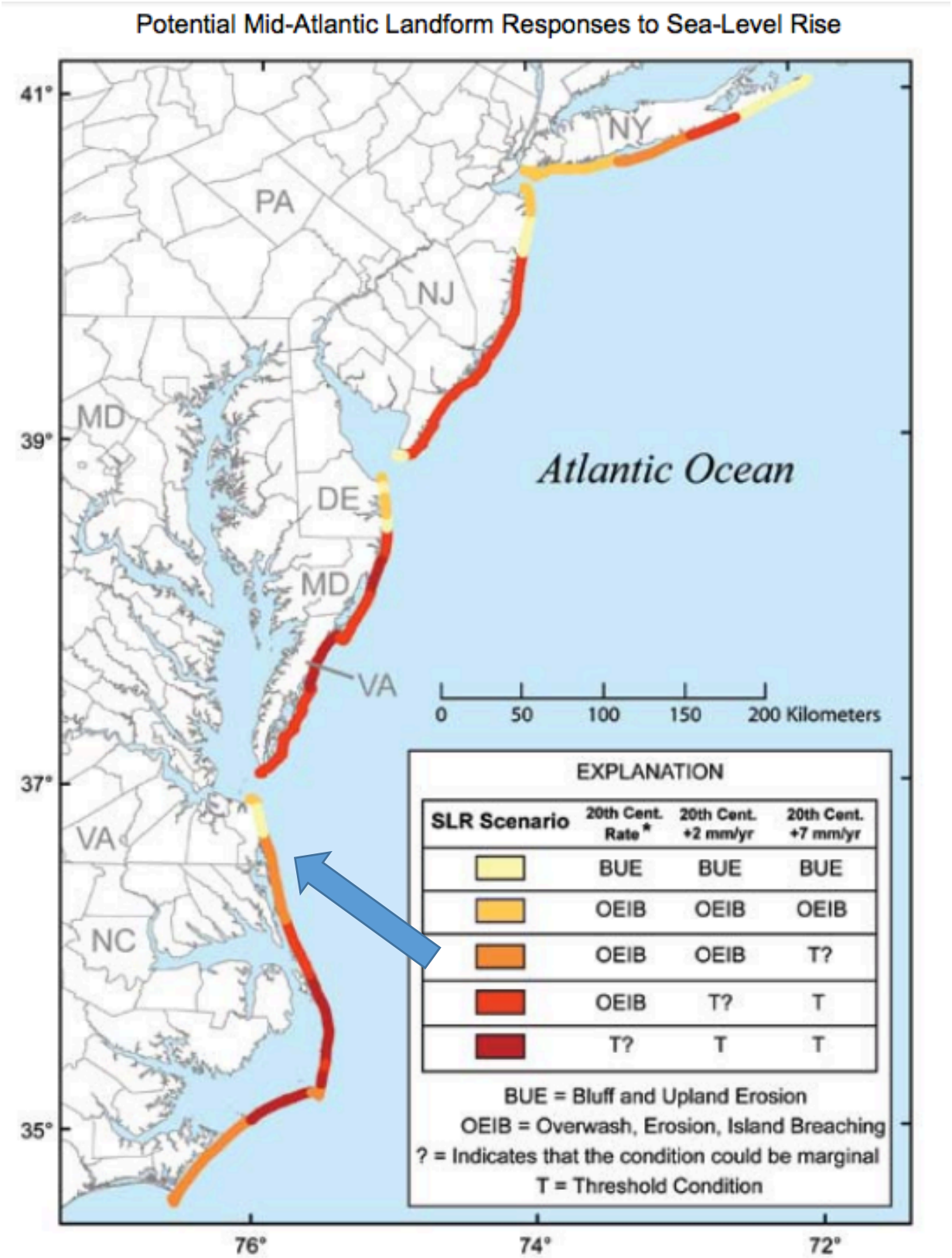

Figure 3. A diagram representing potential responses to shoreline changes due to sea level rise. Back Bay NWR is considered to experience Overwash, Erosion, and Island Breaching (OEIB) at the current rate of SLR and under +2 mm/yr SLR. Under +7 mm/yr scenario, the barrier is expected to reach a marginal threshold condition.

2. Coastal Morphology Under Sea Level Rise at Back Bay NWR

There are many hazards involved with sea level rise in Back Bay NWR. In order to have the ability to adapt to and mitigate some of these hazards going into the future it will be important gain a systems of systems perspective and a comprehensive idea of how different hazards and vulnerabilities interact.

One of the biggest hazards for the barrier island is the interaction of tidal levels and storm surges imposed on a water level baseline that has been risen due to sea level rise (Titus et Al., 2009). In many places the effects of this have already been seen with increased frequency of nuisance flooding along the east coast. When sea level is raised, the baseline is raised then allowing for higher high tides and more intense storm surges. This becomes a problem for low elevation, narrow barrier islands as the risk for breaching events increases dramatically when sea level rise is coupled with hurricane forcing. The hazards resulting from sea level rise for barrier islands can be categorized both ecologically and morphologically and have been well documented and studied.

2.1 Ecological Hazards

If a breach were to occur in Back Bay, salt water would quickly intrude into the freshwater ecosystem. This occurrence of salt water in the bay has been seen previously from both natural and anthropogenic causes. Between the mid and late 20th Century, Back Bay was subjected to salt water pumping twice as a way to increase clarity and boost the fish populations. However, in both cases the spike in salinity created uninhabitable conditions for SAV in the bay as well as disabling a significant amount of freshwater fish eggs and offspring from surviving into adulthood. Additionally, the decline in SAV populations resulted in a decrease in dabbling duck species around the bay (Schwab et Al., 1991). In 1962, another instance of salt water intrusion into the bay occurred, however this was a natural event caused by the Ashe Wednesday storm that devastated the area. This storm created multiple breaches due to storm surge, heavy wave, and aeolian erosion in locations seen in figure 3. The most significant breach points occurred at Little Island Park, south of Bodie Island in False Cape State Park, and along the Virginia – North Carolina border. The days following this massive breach, Ambrossen et Al. recorded a dramatic increase in salinities in the bay, particularly in areas closest to the breach points. Some areas saw salinities as high as 75 percent that of ocean water. At this point, the bay became a highly saline/estuarine ecosystem and many of the freshwater fish populations in the bay such as Largemouth Bass and others were replaced with saltwater species. The American Wigeon population, one of

many migratory waterfowl species, was seen to have been reduced drastically as a result of the salt water intrusion which again killed off much of its food source found in SAV. The Ashe Wednesday storm created a storm surge over 8 feet relative to mean lower low water around Little Creek Island Park and 7.2 feet at Sewell's Point NOAA tidal gauge (MLLW) (Ambrossen et Al., 1962, NOAA, 2016). Since 1962, sea levels have risen a foot or more across the region. As a result, the potential for a breach is heightened as the baseline for storm surge now is a foot higher than it was during the Ashe Wednesday storm; meaning a breach point that once required 8 feet of storm surge to occur now only requires 7 feet of storm surge and the threshold will continue to diminish as sea levels rise and beach/dune erosion continues.

2.2 Morphological Hazards

The morphological hazards associated with sea level rise include erosion, barrier island migration, island segmentation, marsh/wetland loss and total inundation.

Erosion can occur as a product of several different factors and can be accelerated or decelerated under different environmental conditions and anthropogenic interventions. In Back Bay NWR, there are no current beach or dune renourishment projects actively planned or underway as the dunes here are substantial for now and being a refuge, the dune ecosystem is guarded against major anthropogenic disturbances. In the past, the dunes present on the refuge were heightened to act as a natural barrier against surging seas that could wash over the island. With a higher sea level comes a higher high tide which will increase the wave action that is the primary aggrevator of dune erosion. As these higher high tides occur more frequently, the dunes will be subject to scarping or elevation reduction creating a vulnerability in the dune system to breaching events. Often not considered is the effect of sea level rise on the back barrier. The significantly lower elevations of the back barrier create a high risk of island narrowing and reduction of important secondary dune structures under sea level rise in the bay.

Following erosion, island segmentation is then considered as a hazard of sea level rise. Breaching events are known to occur frequently along natural barrier islands and have been recorded in the bast to have happened in Back Bay. These events, along with overwash, are important in the dynamic process of barrier island formation and migration – depositing sediments on the backside of the island to eventually become marsh. Old Currituck Inlet, now filled in, was the northernmost longterm inlet related to Back Bay to have existed in recent history. Its former location was at the Virginia – North Carolina border below False Cape State Park. There is now an extensive marsh/wetland behind this portion of the barrier island, however it remains a low elevation location still subject to ocean breaching as the

dunes are still relatively low in many areas. Sea level rise, even without a breach, can lead to wetland loss as the marshes are inundated from a rising water level in the bay from the Oregon Inlet. If sea levels rise faster than the marsh is able to migrate, loss of this ecosystem can be expected and a destabilization of the back barrier can lead to much faster levels of erosion than the ocean side (Titus et Al., 2009).

3. Response of Barrier Islands to Sea Level Rise Impacts

Low lying, narrow barrier islands, making up 6.5% of the world's open ocean coastline and most of the US eastern seaboard, comprise unique vulnerabilities to sea level rise impacts (Smallegan et Al., 2017). It is important to identify these vulnerabilities to gain an idea of any potential mitigation or adaptation tehniques that can be used to prolong the life of the island and its inhabitants if migration is not an option. The vulnerabilities of Back Bay barrier island include: low elevation, narrow island structure, sand composition, freshwater back bay estruary and impoundment ecosystems, anthropogenic development, and water quality sensitivity of important species. Though significant sea level rise could take many years to inundate or have direct impact, the most immediate, short term hazards such as those from hurricane forcing and extreme weather are going to create more significant impacts. With sea level rise projected to reach 2.5 m or more by 2100 under worst case scenarios, barrier islands under hurricane forcing will see higher potentials for extreme erosion, segmentation, migration or complete inundation.

It is important to note that global mean sea level projections are not accurate projections for regional rise. In the mid-Atlantic region from North Carolina up to New Jersey sea level rise is occurring at rates much faster than the global average of 1.7 mm/year. In Hampton Roads, a rate of 4.61 mm/year indicates that the region is experiencing rise more than double the rate of the rest of the world so one should expect SLR projections in relation to this region to be greater than the global projections. In this case, Back Bay becomes more likely to be impacted by even the low rise scenarios which have a higher probability of occurring. Unfortunately, comprehensive localized SLR studies have not yet been performed so data constraints hinder the ability to make accurate projections for the area.

Even under low SLR scenarios which may not breach the threshold on their own, the heightened water levels will increase the degree of impact from high tides and storm surges – effectively elevating them several feet higher than if they were to happen today. In doing so, the dunes will see greater levels of erosion during these events as wave action reaches new heights - weakening and reducing elevations of the dunes as well as decreasing beach width in front of the dune. These erosive processes will result in a positive feedback loop whereinwhich the

dune/beach height and width will rapidly decline and create more likely conditions for a breach.

In the case of a breach, the salinity levels in the Bay will rise dramatically. A significant impact will be the decline of SAV species located in shallow freshwater zones throughout the bay. SAV has been identified as highly sensitive to saline waters and will not survive in the event of salt water intrusion. This was seen in the aftermath of the Ashe Wednesday storm of 1962 and in the subsequent years of salt water pumping into the bay (Schwab et Al., 1991).

Back Bay is home to or hosts many waterfowl species that use the refuge as an important feeding and resting ground during their migrations such as the American Wigeon. An important reason for this is the estruary; which is able to host an abundance of SAV and invertebrate species that thrive in shallow freshwater conditions of Back Bay. Under multiple sea level rise scenarios, the bay will increase in depth and drown out many marshes and ideal SAV habitats – including the man made impoundments on the refuge. Additionally, in the likely event of a breach in the barrier island, salt water intrusion will decimate the SAV populations and many of the species that rely on them. This means that species such as the American Wigeon will be forced to fly farther and longer to feed and rest which could significantly affect their phenological cycles and ultimately lead to lower survival rates.

Figure 4. The American Wigeon courtesy of the National Audobon Society (2016).

4. Potential Futures Under Sea Level Rise at Back Bay NWR

Under current rates of sea level rise and future scenarios ranging from .3 m up to 2.5 m or more, Back Bay is on track to transition from a freshwater to an estruarine ecosystem as the barrier island becomes inundatated and segmented. Sea level rise comes with a degree of commitment. Sweet et Al. have concluded that even under extremely reduced emmisions scenarios sea levels are expected to continue to rise for the next couple centuries (2017). Using foresight in this area is critical in evaluating risk potentials for Back Bay NWR. It is also important to note that other factors will play important roles in the effects of sea level rise. For example, possible anthropogenic land use change (beach renourishment, sea wall construction or dikes to prevent erosion) in developed areas of Sandbridge beach could have an effect on the longshore sediment deposition that sustains the sediment bank which helps balance the erosive processes on the barrier island.

To identify areas of potential threshold exceedance, topographic maps were utilized. The long-term sea level rise scenarios of Sweet et Al. are paired with storm surge related water levels from the breaches that occurred during the Ashe Wednesday storm of 1962 to determine the current and future thresholds along the most vulnerable points on the island, specifically Little Island Park and Bodie Island. It is also important to note that sea levels in this area have already risen over a foot since the last breach occurred, so even without future SLR the threshold for a breach has been reduced and the lowest points on the barrier island have become more vulnerable. During the 1962 storm, a breach occurred when the water levels reached 7.2 feet above mean higher high water. Today, a storm surge of this magnitude would theoretically only need to reach 6 feet or maybe less in some areas to achieve the same results. Under NOAA's GMSL scenarios and coupled with the fact that this region is experiencing over double the rate of SLR compared to the rest of the world, adequate foresight would agree that Back Bay NWR should expect to be inundated beyond function, even by 2050, unless extreme mitigation and adaptation measures are carried out.

If the barrier island is left to its natural processes without major interference, landward migration should occur until it meets the mainland or stabilizes with a high enough elevation. Along with this process, the Back Bay estruary will be moved westward and inland onto low lying farmland in Pungo. An area of interest for Back Bay would be working with different agencies and organizations in purchasing land with the greatest potential of becoming the next marsh or wetland of Back Bay.

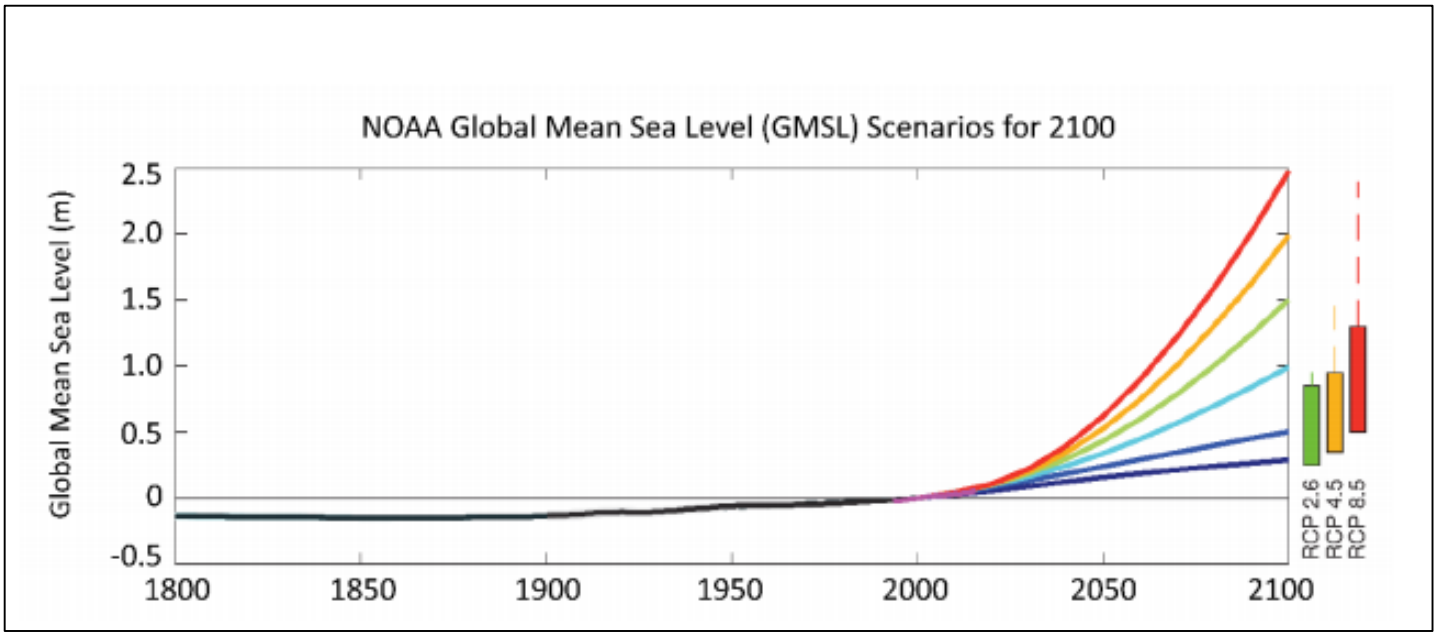

Figure 5. Global Mean Sea Level scenarios going into 2100 show a lower bound of .3 m (a continuation of 20th century trends) up to an upper bound of 2.5 m (a result of severe ice sheet loss) (Sweet et Al., 2017).

The processes that would bring increased water levels to Back Bay, would also carry along the potential for salt water intrusion that could harm the environment biologically and morphologically through increased saline concentrations, changes in water quality/turbidity, hydrodynamics, water temperature, and bathymetry. Back Bay NWR actively manages man made impoundment systems for its migrating and resident bird populations through water control structures and continuous invasive species removal project. The water control structures are important for use in draining or raising water levels in the impoundments. A large pump system was created that can take fresh water from the bay and fill the impoundments when needed. Possibly one of the most certain effects of salt water intrusion on the bay would be the inability for the refuge impoundments to share water with the bay as doing so would result in a significant decrease in freshwater dependent organisms within the impoundment – a direct contradiction to the current goals of the refuge.

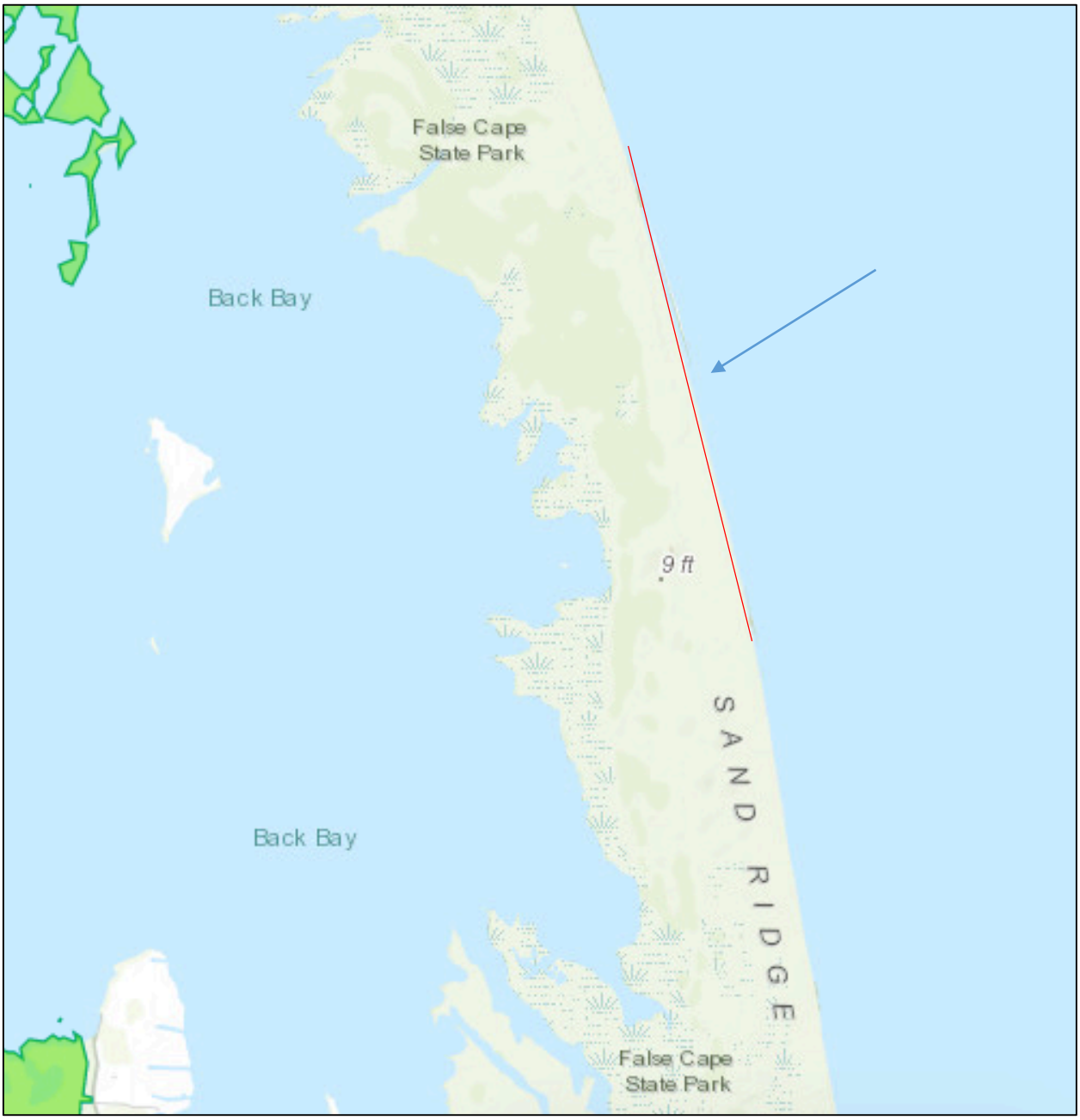

Figure 6. A segment of the barrier island most vulnerable to breaching, erosion, or overwash events. Along this narrow section, the highest elevation of the dune reaches 7-9 feet and the width of the barrier island does not exceed .5 miles. Under sea level rise scenarios of even .5 m, the wetlands on the bay side will become inundated and a storm surge of only 5-6 feet will be necessary to breach the dune (Sweet et Al., 2017; USFWS Refuge Map, 2016).

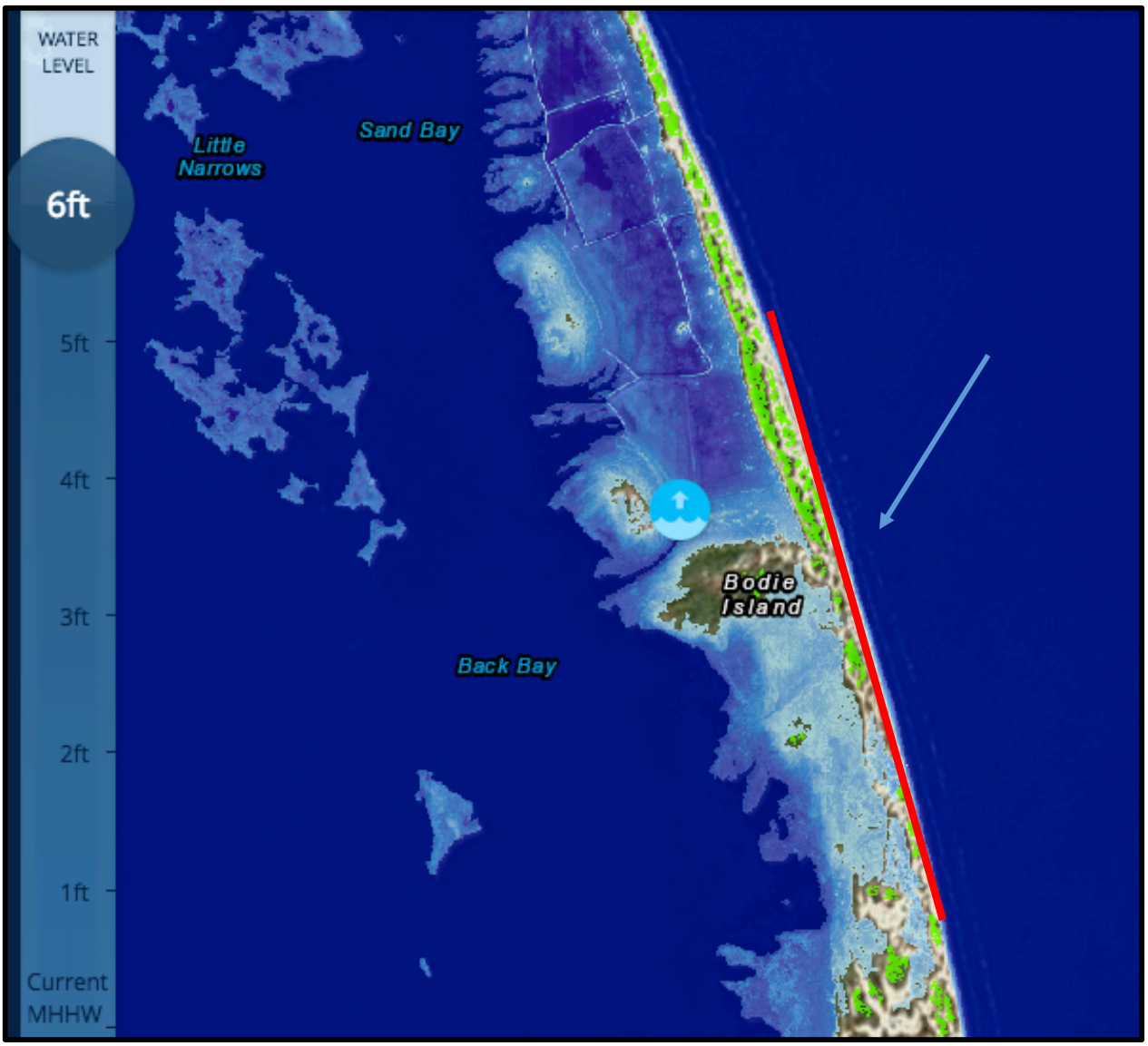

Figure 7. NOAA's Sea Level Rise Viewer representing conditions under a 6 foot sea level rise shows that much of the barrier island will be severely inundated. With the impoundments completely submerged the bay will erode the back barrier of the dune system as the ocean erodes the front. Being a low lying, narrow section of the barrier island, a breach can be expected here soon in the event of a severe storm (NOAA Sea Level Rise Viewer, 2017).

While the method of identifying vulnerable locations is basic, this is an important step to recognize apparent morphological weaknesses in the barrier island so that further research can be done to gain specific knowledge of the site. Some factors maybe overlooked, underestimated or exaggerated in the analysis of these locations, but foresight should be used hand in hand with pragmatic planning and preparation so the worst case scenario is always on the table.

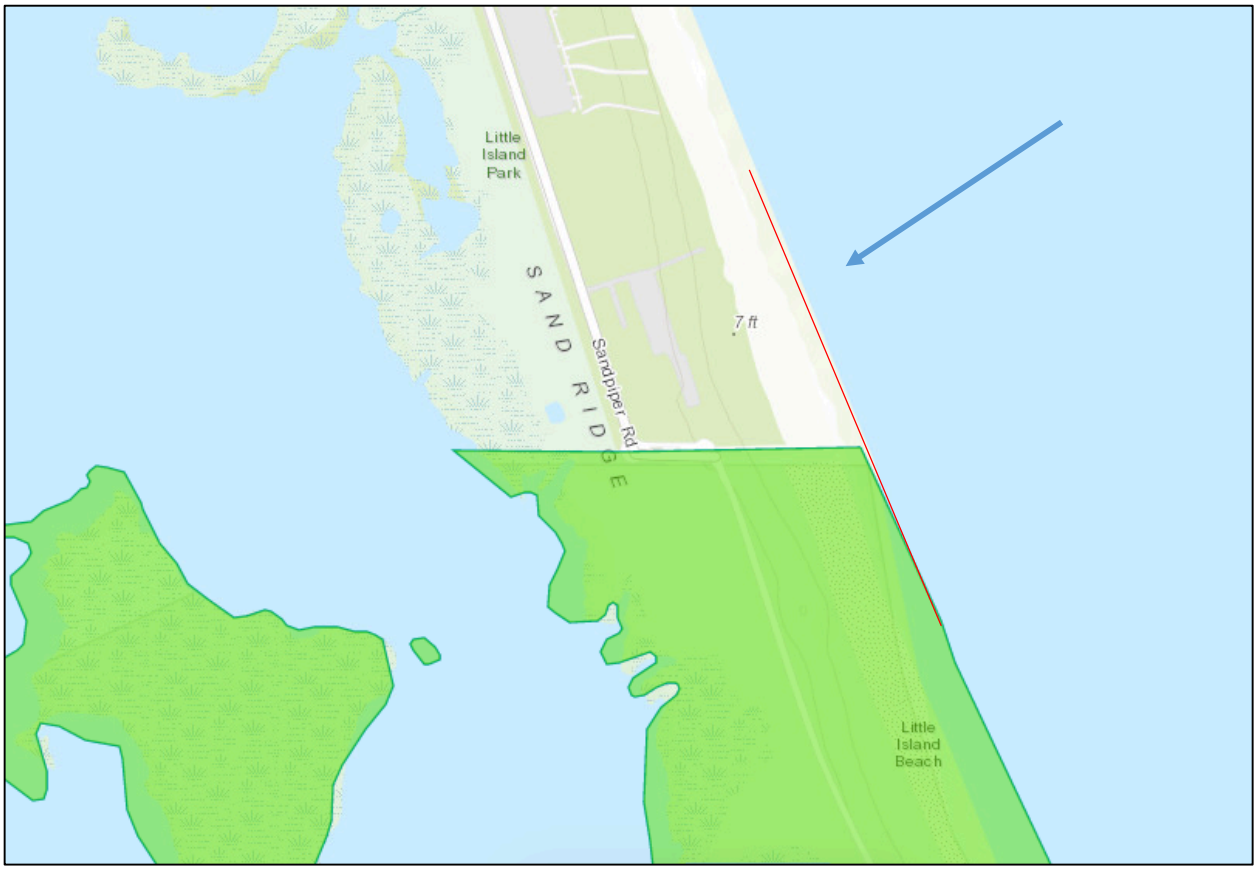

Figure 8. Shows a topographic map of the Little Island Park area. An extremely narrow (.2 miles wide) and low elevation section of the barrier island. Most of the ocean side dune does not exceed 7 feet of elevation making this location highly vulnerable to erosive processes and a likely spot for a breach to occur – an event that has already happen in the past here (USFWS, 2016).

Figure 9. A permanent 6 foot sea level rise scenario represents a worst case scenario by 2100 that would inundate most all of the barrier island. Under severe tropical or northern storms, a 6 foot storm surge is not uncommon, meaning this area could see a breach in the dune system and massice flooding far before sea levels reach 6 feet themselves (NOAA Sea Level Rise Viewer, 2017).

5. Decision Making Process

Decisions regarding sea level rise responses will require coordinated, interagency efforts along with important cooperation between private and public sectors. Back Bay NWR managers and planners will have to work with state, local, and other federal agencies to find solutions and make decisions concerning the beaches of the barrier island as well as acquiring of new lands either through easement or ownership. With the current locations of Back Bay NWR expected to become increasingly prone to flooding and possible segmenation in areas outside of the refuge that will affect the ecosystems and services within the refuge, False Cape State Park along with the local municipality of Virginia Beach, federal agencies such as the US Geological Survey and NOAA, and the private businesses and homeowners in Sandbridge will need to come together to make important, informed decisions on the direction that is most agreeable for all involved stakeholders.

The decision making process can be one of the most difficult to work through. One must have a systems mindset to understand how certain policies of another agency or organization can lead toward the aid or destruction of their own goals. For example, SAV populations are regulated by state agencies, waterfowl and migratory bird populations that depend on these species are managed and protected by the USFWS, while anthropogenic development and land use permits are under the citys jurisdiction. To sustainably produce a solution that addresses all these interests, stakeholders will need to come together as one.

Non-governmental organizations (NGOs) will also play an important role in funding and researching various adaptation and mitigation techniques and processes. Oganizations such as the National Audabon Society, the Viginia Insitute of Marine Science, and many others will be apart of this process.

The importance of public education of these events cannot be discluded either. Holding informative meetings with the public to educate and hold dialogue about possible solutions and needed actions will relieve tensions that could build up if otherwise not addressed. When the public is on board with decisions that can affect their lives the process of decision making becomes much easier.

To summarize, the decision making processes must begin with public education in order to create the atmosphere necessary to facilitate important changes that will help to adapt to or mitigate the effects of sea level rise in the area. Stakeholders should be identified by the leading party to ensure all affected parties are informed and involved. Private organizations, NGOs, and respective governmental agencies should all work together in unison to achieve a desired outcome.

6. Options

Back Bay National Wildlife Refuge will be faced with at least three main options to mitigate and adapt to rising sea levels that can lead to the impacts mentioned in this report. The first option for Back Bay includes utilizing foesight to develop and implement pre-emptive measures that could be taken to alieviate the impacts of sea level rise related hazards on the barrier island. This might include the construction of a sea wall in the most vulnerable locations, beach renourishment projects, dune elevation raising, and the placement of a buried sea wall under the dune. Smallegan et Al. have identified several pathways for adapting to and mitigating sea level rise and storm surge impacts under various scenarios on barrier islands (2017). This option will be the most costly as it requires continuous surveillance and some pathways such as beach renourishment will require continuous and increasing management. Other options such as sea wall construction will demand a large upfront cost and will create additional issues with erosion while disturbing the ecosystem of the dune as well. Smallegan et Al. suggest one of the most effective options would be to create a buried sea wall within the dune and then elevate the dune as well. This, however, does not address the concern of back barrier erosion from the bay under sea level rise. Strategy E in Figure 10 would address this by raising the entire elevation of the island to keep it from becoming inundated. This option would be extremely costly, but would provide increased longevity for the island under most current sea level rise scenarios. The benefits of protecting the refuge from a breach would be to allow the ecosystems behind the barrier island to migrate and adapt to the changing water levels and salinities as they enter in from the southern inlet as well as prolong the ability of the USFWS to manage and protect the area for animals and humans alike.

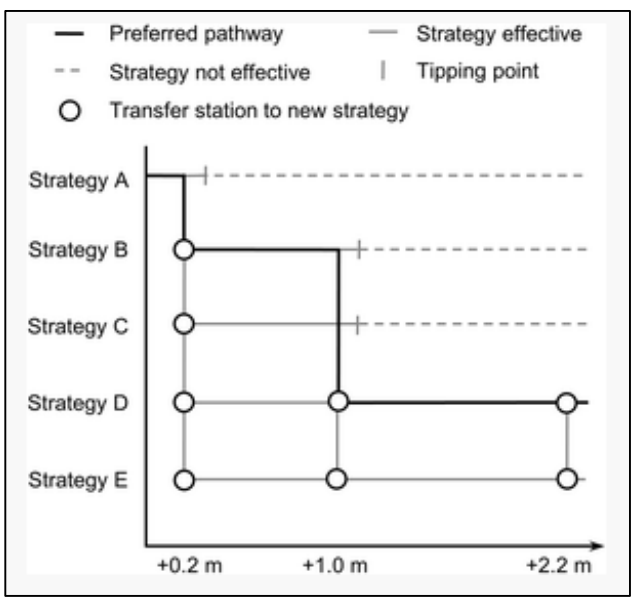

Figure 10. Smallegan et Al. have identified pathways for adaptation and mitigation using different strategies under different scenarios. After determined thresholds are exceeded, the next strategy is implemtented. The last strategies are expensive and require large scale adaptive measures and should be used as a last resort (2017).

The second option for the refuge in regards to sea level rise would be to reactively address the impacts as they occur. This would involve immediately filling in breaches of the barrier island as they occur, heightening existing sea walls on the bay side of the island as flooding becomes more frequent, and repairing any damages to infrastructure as they occur with improvements. This option is requires minimal immediate funding and just requires a plan to be made for the stakeholders in the event of certain scenarios.

The third option the refuge can pursue is a no-action policy that would allow nature to dictate the future of the refuge and bay. Under this option, the refuge would continue with business as usual management techniques. For example, if a breach occurs that creates an inlet, the policy would avoid any anthropogenic intervention in this process as it is a natural and necessary occurrence on barrier islands and by closing it, the barrier island will be hindered in the long run as it will be unable to migrate at a pace equal to sea level rise. While this will mean many of the current functions of the refuge will need to be redefined, it does not mean an end to the refuge itself. Many of the freshwater species in the refuge will decline in abundance, but as seen in the past, saltwater and brackish species will fill in the niche gaps to create a new ecosystem in this estruary. Additionally, the marsh and wetland zones of the bay will naturally migrate or emerge in new locations. Identifying these locations and working with partners to aquire the land will help ensure future protection of these habitats and provide Back Bay NWR the ability to continue functioning in its purpose.

7. Recommendations

After identifying many of the barrier island impacts and responses to sea level rise, it is clear that one of the biggest impacts will be a breach in the barrier island and the resulting effects. It is no longer a question of whether this event will occur but rather of when and to what extent. Using foresight, the near-term future of the barrier island under current sea level rise trends, which are already high for this region and are expected to accelerate, depends on the level of management implemented. Eventually, sea level rise is expected to become so severe that retreat will be necessary. As a refuge whose primary goal is to provide protection and habitat for the local species, over management may actually backfire by hindering the processes that have occurred naturally for thousands of years.

As a recommendation, I would suggest that stakeholders engage in minimal management against major sea level rise impacts; siding with option three. However, I recognize that special interests of the private sector involved with the tourism industry may not agree with this plan and will fight to maintain its

function. Working with these parties to make educated decisions is important and this might mean compromising on certain decisions. Large investments will need to be protected for as long as possible in Sandbridge, so sea walls and renourishment projects can be expected. I forsee that these changes will only be effective in the short term future but ultimately they become ineffective as sea levels climb higher and storms become more intense. Over the next several years, instead of spending excessive money on protecting the barrier island, it will be more beneficial to proactively find and acquire land will become apart of the new Back Bay National Wildlife Refuge.

8. Appendix

While this report addresses sea level rise thresholds, impacts, and responses through a collection of empirical reports and personal analysis of data trends, there are several areas of study that were not covered in this report that may be helpful in gaining better understanding of the future of Back Bay NWR. Employees of Back Bay NWR, stakeholders, and future interns could address these deficiencies with further research. I did not have the means to create probabilistic scenarios on the rate by which salt water might intrude the bay from the south, this could help balance a decision to allow or fight a breach depending the timeframe of intrusion into Back Bay. Additionally, some other processes may have been overlooked that could reduce or increase the liklihood of a breach on Back Bay (i.e. the effect of longshore sediment deposition on the barrier island under changing oceanic currents and rising sea levels). Unfortunately, some deficiencies were present in this research as ocean side mean tidal level data was sparse, so trends in SLR were assumed as equal with the Sewells Point tidal gauge. Along with this, dunes are subject to increases and decreases in elevation on yearly scales due to aeolian distributions, wave action, etc.. so topographic data is likely to be outdated.

Climate change will bring about many more impacts apart from sea level rise and these should be researched and coupled with this report to achieve a higher degree of understanding and foresight for the refuge, its ecosystems and many species. Stakeholders should not exclusively use this report to make decisions, its purpose is to be used as a tool or reference that can encourage dialogue about the subject and subsequently act as a springboard for further, more in-depth research.

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