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Getting that Sinking Feeling: Analysis and Impacts of Sea Level Rise on Three National Parks along the East Coast, USA

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Abstract

Due to global climate change, sea level rise (SLR) has become a threat for future generations, but the extent of this danger is unknown. To help understand the possible effects of SLR on the east coast of the United States, we studied three national parks: Acadia National Park (ACAD), Assateague Island National Seashore (ASIS) and Everglades National Park (EVER). We predicted that ACAD would be less affected by SLR than ASIS and EVER due to the construction of its beach profile. By measuring the beach profile, we found that Sand Beach in ACAD was reflective with an average slope of 3.2 cm/m while South Ocean Beach in ASIS had an intermediate morphology with an average slope of 1.57 cm/m. The Snake Bight Channel beach in EVER was dissipative and had no slope. Using historical Landsat imagery from 1984 to 2016, we estimated that ACAD's water area increased by 1.61%, that ASIS's water area increased by 2.47%, and that the EVER's water area decreased by 0.22% between 1992 and 2011. Using RCP scenarios from the latest IPCC report, we estimated future inundation levels in each park along with the percent change between the best and worst-case scenarios. Under the RCP8.5 scenario, ACAD had 1.36 km2 of inundation, ASIS had 37.11 km2, and EVER had 366.47 km2. ACAD had the highest percent change between the worst and best RCP scenario at 15.70%. ASIS had a slightly smaller percent change at 14.25% and EVER had even less at 10.42%. This study suggests that continued SLR will cause national parks billions of dollars in property damage and the loss of their inherent ecological value.

Keywords

sea level rise, national parks, Everglades, Acadia, Assateague, arcGIS

Disciplines

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Comments

Written as an Environmental Studies Senior Capstone.

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We affirm we have upheld the highest principles of honesty and integrity in our academic work and have not witnessed a violation of the honor code.

Abstract

Due to global climate change, sea level rise (SLR) has become a threat for future generations, but the extent of this danger is unknown. To help understand the possible effects of SLR on the east coast of the United States, we studied three national parks: Acadia National Park (ACAD), Assateague Island National Seashore (ASIS) and Everglades National Park (EVER). We predicted that ACAD would be less affected by SLR than ASIS and EVER due to the construction of its beach profile. By measuring the beach profile, we found that Sand Beach in ACAD was reflective with an average slope of 3.2 cm/m while South Ocean Beach in ASIS had an intermediate morphology with an average slope of 1.57 cm/m. The Snake Bight Channel beach in EVER was dissipative and had no slope. Using historical Landsat imagery from 1984 to 2016, we estimated that ACAD's water area increased by 1.61%, that ASIS's water area increased by 2.47%, and that the EVER's water area decreased by 0.22% between 1992 and 2011. Using RCP scenarios from the latest IPCC report, we estimated future inundation levels in each park along with the percent change between the best and worst-case scenarios. Under the RCP8.5 scenario, ACAD had 1.36 km^2 of inundation, ASIS had 37.11 km^2, and EVER had 366.47 km^2. ACAD had the highest percent change between the worst and best RCP scenario at 15.70%. ASIS had a slightly smaller percent change at 14.25% and EVER had even less at 10.42%. This study suggests that continued SLR will cause national parks billions of dollars in property damage and the loss of their inherent ecological value.

Introduction

In recent years, the Intergovernmental Panel on Climate Change (IPCC) has determined that there is “unequivocal evidence” that the climate is changing across our planet, largely as a result of human activities (IPCC Fifth Assessment Report 2013). Humans enhance the greenhouse effect directly by emitting greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) (IPCC Fifth Assessment Report 2013). Climate change causes extreme weather events, and it is important that scientists begin to study the long-term effects of climate change in order to help mitigate these severe consequences.

One of the major impacts that climate change will have on oceans around the world is a change in sea level, which is the height of the ocean surface at any given location. Sea level is measured using tide gauges from the present through the past few centuries and estimated for longer time spans from geological records (IPCC Fifth Assessment Report 2013). Sea levels around the world are rising due to thermal expansion of seawater due to the warming ocean temperatures and increasing amounts of water from the melting of glaciers and polar ice caps (IPCC Fifth Assessment Report 2013). Sea level data indicate a transition in the late nineteenth century to the early twentieth century from relatively low mean rates of sea level rise (SLR) to higher mean rates. Global mean SLR has continued to increase into the twenty-first century (IPCC Fifth Assessment Report 2013). The global average sea level has risen at an average rate of 1.7 mm/yr since 1901 and at an average rate of 3.1 mm/yr since 1993 (IPCC Fifth Assessment Report 2013).

SLR will be detrimental along the East Coast of the United States because of the variety of coastal habitats present along its shores. Many of these habitats are present within the boundaries of national parks, which were originally designed to protect them from human impact.

Acadia National Park

Acadia National Park (ACAD) is located in Maine, mostly on Mount Desert Island and other small islands off the Atlantic Coast (Figure 1). Over the last hundred years, sea level has risen in New England at rates ranging from 0.6 to 2.5 mm/year (Nielsen and Dudley 2011). Over 20% of ACAD is classified as wetland (Natural Features & Ecosystems, n.d.). To keep up with the rising sea level, salt marsh surfaces need to increase their height above sea level through sediment accumulation and peat growth (Nielsen and Dudley 2011). Ecologically, the salt marshes of ACAD are important because they filter nutrients, sediments, and contaminants from waters entering the coastal zone (Nielsen and Dudley 2012). Detritus resulting from the decay of marsh plants and animals provide steady food for coastal food webs. They are refuge and breeding habitats for many fish, migratory birds and other wildlife species (Nielsen and Dudley 2012). ACAD’s tourism will also be affected due to SLR. The salt marshes of ACAD are important for not only their ecological value but also their aesthetic beauty. SLR will also impact Sand Beach, a popular tourist destination in the park in the summer months (Natural Features & Ecosystems, n.d.).

Assateague Island National Seashore

Assateague Island National Seashore (ASIS) is located on Assateague Island, a thirty-seven mile long barrier island located off the coast of Maryland and Virginia (Figure 2). Barrier islands form when sand deposits build up due to ocean currents or storms and are cut off from the mainland due to natural changes in sea level (Ritter et al. 1995). However, barrier islands like ASIS are threatened by SLR, which causes the process of landward rollover or island rollover.

This rollover occurs when increasing sea levels and storm intensities caused by climate change deposit sands at high rates until the barrier island reaches a maximum width forcing the island to migrate inland or risk becoming flooded (Assateague Island Coasts/Shorelines n.d.; McBride et al. 1994). Tide gauges near Assateague Island indicate an average increase of about 3.39 mm/year just to the north of the national seashore and about 3.58 mm/year just to the south (Assateague Island National Seashore Geologic Resources Inventory Report 2013).

Everglades National Park

Everglades National Park (EVER) is located on the southern tip of Florida (Figure 3). This national park is unique compared to the other parks because of its low elevation and subtropical climate. Along the coast, seasonal pulses of freshwater from the north merge with the ocean currents providing several diverse ecosystems. These coastal communities are home to many rare and endangered plants and animals (Sea-Level Rise In Everglades National Park n.d.). Mangrove forests are one of the most productive ecosystems on Earth with a mean production of 2,500 mg C m-2 per day (Jennerjahn and Ittekkot 2002). Mangroves are salt tolerant trees located along tropical coasts of Florida (Simard et al. 2006). They also act as a buffer between the land and sea reducing the impact of storm surge, waves, and erosion of the shoreline (Simard et al. 2006). SLR can cause an increase in inundation levels as well as an increase in saltwater disturbance. These changes put pressure on EVER ecosystems causing inland migration of plants, variation in species composition, and disruption of key predator-prey relationships (Stabenau et al. 2011).

Study Purpose and Hypothesis

The purpose of this study is to examine how changes in SLR could potentially impact these three national parks located along the East Coast of the United States. We will analyze the amount of area threatened by inundation within each park. We hypothesize that Acadia National Park will be less affected by SLR than Everglades National Park and Assateague Island National Seashore because of the morphology of its beach profile.

Materials and Methods

In order to test our hypothesis, we first created a beach profile for the three national parks. Each beach profile was created by measuring the changes in elevation in centimeters (cm) over the distance from the swash zone to the dunes in meters (m). Using a measuring tape, we marked off the distance every 2 m starting at 1 m from the waterline and moving perpendicularly up the beach. We used two profiling poles to measure the vertical drop by visually estimating where the horizon line coincided with the pole closest to the water. We then determined how many centimeters of elevation change there was between the two profiling sticks. In order to graph the beach profile, we added the changes in elevation together to calculate the cumulative elevation at each measurement location and graphed the cumulative elevation versus the distance.

The beach profile at ACAD was measured at Sand Beach. We took measurements on March 11th, 2017 at low tide starting at 4:00pm. We measured two transects 25 m apart. The first transect was located at GPS coordinates 44°19’44’’N and 68°10’58’’ W and the second was located at 44°19’44’ N’ and 68°10’57” W. We then averaged the total slope of both transects to get an average slope.

The beach profile at ASIS was created for a section of South Ocean Beach using three different transects 26 m apart. The data were collected on March 4th, 2017 at low tide starting at 5:55am. The first transect was located at GPS coordinates 38°11’24’’N and 75°9’24’’W. The second transect was located at 38°11’23’’N and 75°9’24’’W. The third transect was located at 38°11’22’’N and 75°9’24’’W. We then calculated the average slope across all three transects.

Due to the time and budget constraints of the study, we were unable to travel to EVER to measure the beach profile using the same methods as mentioned previously. Instead, we constructed a digital beach profile using Google Earth’s ruler and elevation profile capabilities. We measured two transects 175.9 m apart. The first transect was located at 25°09’45.00”N and 80°53’46.48”W. The second transect was located at 25° 09’48.17’’N and 80°53’47.37”W. We also calculated the average slope across both transects.

We accomplished the historical analysis by comparing Landsat images downloaded from EarthExplorer. We used images taken in 1984 given by Landsat 5 and images taken in 2016 by Landsat 8. For ACAD and ASIS, we downloaded one image for each year. Each image was taken during the summer season and had less than 10% cloud cover (Table 1). We clipped the Landsat images down to the size of each park using an National Park Service (NPS) boundary shapefile downloaded from the NPS Integrated Resource Management Applications (IRMA) data store and conducted an iso-cluster unsupervised classification of 30 classes. We reclassified them down to three classes: beaches, water, and land. To ensure accuracy, we picked two locations that looked to have the most change and set up 50 random points in each location. EVER required a different data source due to cloud interference in the Landsat images. These clouds reflected very closely to water and the classification system could not differentiate between land beneath the cloud’s shadow and water beneath the shadow. Instead, we used National Land Cover Dataset (NLCD) rasters and clipped them down to the EVER shapefile, and manually reclassified them to land and water types.

We conducted our analysis of the impacts of future SLR on the three parks using the ArcMap 10.3.1 program. Similar to other studies conducted by Akumu et al. (2010) and Mahapatra et al. (2015) to monitor SLR along regional coastlines, our study analyzed the areas of inundation within each park by comparing current elevations of their beaches with sea levels adjusted for the three IPCC projections. For each park, we created three maps showing the amount of area that would be inundated under three different IPCC projections: the RCP2.6, the RCP4.5, and the RCP8.5. The RCP2.6 scenario shows the least amount of SLR at 0.40 m by the end of the century (IPCC Fifth Assessment Report 2013). Each RCP (Representative Concentration Pathway) scenario was created based on possible trajectories of greenhouse gas concentrations in the atmosphere (Caffrey et al. 2013). The RCP8.5 scenario shows the greatest amount of SLR at 0.63 m by the end of the century (IPCC Fifth Assessment Report 2013). The RCP4.5 scenario is one of two moderate projection scenarios at 0.47 m, but has a greater rate of rise earlier in this century which makes it more relevant to study the potential threat of SLR against the parks than the moderate RCP6.0 scenario (IPCC Fifth Assessment Report 2013).

Each map was created by selecting for all areas less than or equal to the new level given by the IPCC projection based on methods provided by the NOAA Office of Coastal Management (2017). We then calculated the area of inundated land and land that would remain non-inundated in kilometers (km). We used digital elevation models (DEMs) downloaded from the United States Geological Survey (USGS) National Map Viewer to conduct this analysis. The DEMs had a resolution of 1/9 arc-seconds for ACAD and ASIS. This resolution was assumed equivalent to 3.4 m for use in the calculations. For EVER, we used a resolution of 1/3 arc-seconds which was assumed equivalent to 10 m.

Results

Beach Profiles

Sand Beach at ACAD had the highest average slope of 3.2 cm/m. The beach has a reflective profile with a steeper, linear beach face and shorter berm than ASIS or EVER. South Ocean Beach at ASIS had an average slope of 1.57 cm/m. The beach has a more intermediate morphology between reflective and dissipative. The beach face has a noticeable incline but not as steep as Acadia but the berm is much longer (Figure 4). According to the digital beach profile on Google Earth, the beach at Snake Bight Channel in the EVER had the lowest average slope of 0 cm/m. This beach has a more dissipative morphology with a low angle and gently sloping beach face and swash zone than the other two beaches (Figure 5).

Historical Imagery

ACAD saw the least amount of change from 1984 to 2016. Beach area decreased by 0.01%, and water area increased by 1.61% (Figure 6). ASIS saw more change over the 32 year period: beach area decreased by 0.64%, and water area increased by 2.47% (Figure 7). The most amount of visible change occurred in EVER. Water area actually decreased by 0.22%. Visually, the wetland areas in EVER increased (Figure 8).

Future Projections

For ACAD, almost all the area (99%) in each of the three IPCC projections was considered non-inundated. The RCP2.6 scenario showed an inundated area of 1.17 km^2 (Figure 9) while the RCP4.5 scenario showed an inundated area of 1.2 km^2 (Figure 10). The RCP8.5 scenario showed the largest inundated area of 1.36 km^2 (Figure 11). Between the RCP2.6 scenario and the RCP4.5 scenario there was a 3.42% change in inundation. There was a 15.70% change in inundation between the RCP2.6 scenario and RCP8.5 scenario (Table 2).

For ASIS, the smallest inundated area was RCP2.6 scenario with 32.48 km^2 (Figure 12). The middling inundated area was the RCP4.5 scenario with 34.02 km^2. (Figure 13). The largest inundated area was the RCP 8.5 scenario at 37.11 km^2 (Figure 14). Between the RCP2.6 scenario and the RCP4.5 scenario there was a 4.74% change in inundation. There was a 14.25% change in inundation between the RCP2.6 scenario and RCP8.5 scenario (Table 3).

For EVER, the smallest inundated area was the RCP 2.6 scenario with 306.59 km^2 (Figure 15). The middling scenario was RCP 4.5 scenario, which had an inundated area of 334.51 km^2 (Figure 16). The largest inundated area was the RCP 8.5 scenario at 366.47 km^2 (Figure 17). Between the RCP 2.6 scenario and the RCP 4.5 scenario there was a 9.11% change in inundation. There was a 10.42% change in inundation between the RCP 2.6 scenario and RCP 8.5 scenario (Table 4).

Discussion

Based on the results of our analysis, our hypothesis that ACAD would be the least affected by rising sea level because of its morphology was correct. The trend of ACAD being the least affected out of the three parks can already be observed. Our analysis of the time period between 1984 and 2016 shows that while ACAD has already seen a rise in sea level along its coasts, it did not experience as much of an increase as the other parks. The analysis further shows that this trend will continue into the future as well. In each of the three IPCC projection analyses, ACAD had the least potential for flooding. A previous study conducted by Thieler and Hammar-Klose states that Maine’s coastline shows a relatively low vulnerability to future SLR due to its steep coastal slopes, rocky shoreline characteristic of the region, and large tidal range (1999). These studies agree with the results shown in our beach profiles. ACAD had a more reflective beach profile than both ASIS and EVER, with the steepest beach face (Ritter et al. 1995). These steeper beach faces result in most of the park's coastal zone lying at least 3.5 m above mean sea level (Graham 2010). However, some areas on the eastern coast of Mount Desert Island are less than 1.5 m above mean sea level (Graham 2010). These low areas on the east coast, like Sand Beach, will still be flooded by the rising sea level.

One interesting pattern that appeared in our analysis was that ACAD saw the greatest percent increase between the best-case scenario and the worst-case scenario, the largest change out of the three parks. This suggests that while the other two parks would see greater impacts from SLR even with best case conditions, it would take worse conditions for ACAD to show more of an impact. There are many factors that have to be taken into consideration in the future in order to see if the trend is realistic. The biggest factor that would impact ACAD alone over the other two parks would be isostasy, the change in land level due to the removal of a mass such as a glacier or ice sheet (Caffrey et al. 2013). Maine was once located under the Laurentide Ice Sheet, a glacier which depressed the land underneath it. After the glacier melted away, the land has started to rebound and many areas along the northeastern coast have seen decreased sea levels as a result (Caffrey et al. 2013). If ACAD's land continues to rebound, it could potentially mitigate future SLR; however, if the rate of SLR occurs too quickly as it could in the worst case scenario, the rate of rebound would not be able to counteract it.

The results of our study are important to consider because of the potential damage rising sea level will cause in ACAD. Important natural ecosystems, such as the salt water marshes, will be impacted by the rising sea levels. As our data suggests, under all three IPCC projection scenarios the marsh behind the dune ridge at Sand Beach would be inundated. In the past, marshes have responded to the increases in SLR by sediment accumulation and upland migration

(Schile et al. 2014). However, due to the extreme increases in SLR projected, salt water marshes would not be able to keep up. The increased inundation levels and the decreases in sediment accumulation would decrease overall plant productivity, threatening ecological food webs (Schile et al. 2014). Not only would the rising sea levels cause damage to the natural ecosystem, they would also cause damage to the human infrastructure and the cultural importance of the park. According to a study conducted by the National Park Service, ACAD could face up to $741,643,375 in damages to its infrastructure (Peek et al. 2015). While Peek et al. used a 1 m projection, the amount of economic damage highlights the high cost and the extent of damage to the park.

Like ACAD, ASIS has also already been affected by SLR; however, it was slightly more affected by past SLR than ACAD was during the 32 year period. This difference is attributed to ASIS's shallower beach profile and the higher rate of SLR off the coast of Maryland than Maine. Its beach profile looks more dissipative, with clearly defined beach features such as its berm (Ritter et al. 1995). Based on the future inundation analysis, ASIS will increasingly be affected by SLR on a greater scale than ACAD as well. ASIS had the next least potential for flooding under all three IPCC projections; however, there was a large difference in the factor of amount of land inundated in ACAD (<2 km^2) and ASIS (>30 km^2). The percent change between RCP2.6 and RCP8.5 was 14.25% which was the second largest of the parks after ACAD. However, SLR would have a greater impact on ASIS than ACAD because ASIS is at a higher risk of exposure to inundation (Peek et al. 2015).

If the rate of SLR increased based on the IPCC projections, it would greatly impact the rich variety of ecosystems and species that live on the barrier island. The island is home to habitats including marshland, forest, shrubland, sand dunes, and beaches, each with unique ecosystem services that they provide. These ecosystems are threatened by sea level rise not only because of inundation threat but because of natural geomorphic processes. Increased sea levels disturb the sand balance which puts barrier islands out of equilibrium and causes them to deplete (Pilkey and Cooper 2014). Barrier islands would also undergo the process of island roll over more frequently as the sands are pushed backward (Pilkey and Cooper 2014). Like ACAD, ASIS would also face economic consequences from future SLR. The estimated loss of infrastructure and cultural assets could reach $141,894,898, a price lower than ACAD's but still reflective of the severity of SLR (Peek et al. 2015).

Based on our results, EVER was most affected by rising sea level in comparison to ACAD and ASIS because of its beach morphology. EVER had the greatest potential for flooding under all three IPCC projections with a larger difference than the other two parks (>300 km^2). Snake Bight Channel is extremely flat with very few deviations from zero. Over 300 km^2, including the Snake Bight Channel beach, was inundated even in the best case scenario. EVER had the smallest amount of change between the two extreme RCP scenarios, which could be due to the park's immense size. Its susceptibility to SLR is higher because of its low elevation and flat landscaping. The majority of flooding occurs in the western and southern parts of the park while the northeast corner remained mostly unchanged; this could be because of the poorer resolution of the data in that area.

The historical imagery from 1992 to 2011 showed a decrease in water area and an increase in wetland area, which can be attributed to natural feedback mechanisms found in wetlands. As the water rises, transport and deposition of sediments is enhanced, allowing for accumulation of sediments at the appropriate elevation (Chambers et al. 2014). This mechanism will not be able to keep up with the rate of SLR, which is predicted to accelerate faster (IPCC 5th

Assessment Report 2013). It is assumed that the disappearance of freshwater in the northeastern section of EVER is likely not due to SLR, but to evaporation because of increasing air temperatures.

Even in the best case scenario, essential ecosystems would be partly or entirely submerged in water. If sea level continues to rise at this alarming rate, the sandy and mangrove coasts of south Florida will erode and salinity levels in low-lying freshwater wetlands will increase (Wanless et al. 1997). Research conducted by Short et al. on the impact of climate change on wetland plants has shown that with increases in salinity, primary productivity has decreased in EVER sawgrass-dominated areas (2016). This suggests that an increase in saltwater intrusion could impact not only freshwater marsh productivity but also change the species composition of these ecosystems. To keep pace with the higher tides, prolonged flooding and increased tidal energy from SLR, mangrove forests have also moved inland in a process called mangrove encroachment (Short et al. 2016; Yao and Liu 2017). Similar to ACAD , EVER would face large economic consequences from future SLR. The estimated loss of infrastructure and cultural assets could reach $657,087,096 (Peek et al. 2015). This price is lower than ACAD’s but still significantly higher than ASIS’s.

Climate change is projected to increase storm intensity for hurricanes due to rising ocean temperatures. Stronger hurricanes will lead to higher amounts of flooding due to storm surges (Murdukhayeva et al. 2013). With rising sea level, storm surges will be more damaging due to the already heightened surface waves (Ritter et al. 1995). Areas with steep beach morphology such as ACAD or more developed dunes in ASIS would help mitigate some of this damage. Overwash resulting from storm surges would be unable to move further inland because the dunes or steep beach face would hinder the water’s movement (Ritter et al. 1995). In areas without these protections such as EVER, our worst-case RCP 8.5 scenario could be a conservative estimate for inundation because it does not take into account possible overwash from future storm surges. For future studies, a fluid study including changes in geomorphology as storm surges and SLR occur would be beneficial in creating a more realistic environmental model because as beach morphology changes, inundation patterns will change (Murdukhayeva et al. 2013). Tidal variations could also be used in GIS analysis to gain a more detailed understanding of how SLR would change based on high and low tides (NOAA Office for Coastal Management 2017).

There were several limitations to our study. When conducting the beach profiles at both ACAD and ASIS, the measurements might not be completely accurate due the measuring poles being curved. Specifically for ACAD, we were unable to complete a third transect. Another limitation is that the historical Landsat imagery and the NLCD does not differentiate between saltwater and freshwater so our data included both water types. Also when using the NLCD for EVER, there was no specific beach classification like there was for the historical Landsat imagery. The NLCD used a twenty year time frame instead of a thirty year time frame. Finally, we used ⅓ arc-second data for the IPCC projection scenarios in EVER rather than 1/9 arc-second. This decreased the spatial resolution by 6.6 m. As a result, the analysis is less accurate because the elevations are more generalized for larger areas. Some areas that might have been flooded did not appear inundated, or estimated inundated areas may not be under water.

Conclusion

Based upon our results, we accept our hypothesis that ACAD would be more affected by SLR than ASIS and EVER. Moving forward, we should be more aware of anthropogenic activities that directly increase CO_2 in the atmosphere, which also directly affects CO_2 levels in the ocean. Increased CO_2 in the atmosphere causes sea surface temperatures to increase, as well as atmospheric temperatures, causing glacial melt and thermal expansion in the water. The threat of SLR indicated in our study would cause coastal national parks millions of dollars, force habitats and species to migrate inland or adapt to the changing climate, and destroy important cultural and historic sites. The results of our study show that even with the best case scenario of curbing greenhouse gas emissions, SLR will still cause extensive damage in the national parks. It emphasizes the need for more immediate efforts to change our behavior in order to mitigate the impacts of climate change and avoid the damage of a possible worst case scenario.

References

Akumu C.E., Pathirana S., Baban S., Bucher D. 2011. Examining the potential impacts of sea level rise on coastal wetlands in north-eastern NSW, Australia. Journal of Coastal Conservation 15(1): 15-22.

Caffrey M. and Beavers R. 2013. Planning for the impact of sea-level rise on US national parks. Park Science 30(1): 6-13.

Chambers L.G., Davis S.E., Troxler T., Boyer J.N., Downey-Wall A., Scinto L.J. 2014. Biogeochemical effects of simulated sea level rise on carbon loss in an Everglades mangrove peat soil. Hydrobiologia 726: 195-211.

Graham J. 2010. Acadia National Park: geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2010/232. National Park Service, Ft. Collins, Colorado.

Jennerjahn T.C. and Ittekkot V. 2001. Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. Naturwissenschaften 89: 23–30.

Mahapatra M.R., Ramakrishnan A., Rajawat S. 2015. Coastal vulnerability assessment of Gujarat coast to sea level rise using GIS techniques: a preliminary study. Journal of Coastal Conservation 19(2): 241-256.

McBride R.A, Byrnes M.R., Hiland M.W. 1994. Geomorphic response-type model for barrier coastlines: a regional perspective. Marine Geology 126: 143-159.

Murdukhayeva A., August P., Bradley M., LaBash C., Shaw N. 2013. Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. Journal of Coastal Research 29: 1-16.

National Park Service. Assateague Island Coasts/Shorelines. n.d. Retrieved from: https://www.nps.gov/asis/learn/nature/coasts.htm

National Park Service. Natural Features & Ecosystems. n.d. Retrieved from: https://www.nps.gov/acad/learn/nature/naturalfeaturesandecosystems.htm

National Park Service. Sea-Level Rise in Everglades National Park. n.d. Retrieved from: https://www.nps.gov/ever/learn/nature/cceffectsslrinpark.htm

Nielsen M.G. and Dudley R.W. 2012. Estimates of Future Inundation of Salt Marshes in Response to Sea-Level Rise in and Around Acadia National Park, Maine. Scientific Investigations Report 5290: 1-17.

Nielsen M.G. and Dudley R.W. 2011. Inventory and Protection of Salt Marshes from Risks of Sea Level Rise at Acadia National Park, Maine. U.S. Department of the Interior Fact Sheet 2011-2015: 1-4.

NOAA Office for Coastal Management. 2017. Detailed Method for Mapping Sea Level Rise Inundation [Internet]. Silver Spring (MD): National Oceanic and Atmospheric Administration; [cited 2017 April 15]. Available from https://coast.noaa.gov/data/digitalcoast/pdf/slr-inundation-methods.pdf

Peek, K. M., Young R. S., Beavers R. L., Hoffman C. H., Diethorn B. T., Norton S. 2015. Adapting to climate change in coastal national parks: Estimating the exposure of park assets to 1m of sea-level rise. Natural Resource Report NPS/NRSS/GRD/NRR—2015/961. National Park Service, Fort Collins, Colorado.

Pilkey O.H. and Cooper J.A.G. 2014. Are Natural Beaches Facing Extinction?. Journal of Coastal Research 70: 431-436.

Ritter D.F., Kochel R.C., Miller J.R. 1995. Coastal Processes. In: Process Geomorphology, 3rd Edition. WC Brown Publishers. Dubuque IA, USA.

Schile L. M., Callaway J. C., Morris J. T., Stralberg D., Parker V. T., Kelly M. 2014. Modeling Tidal Marsh Distribution with Sea-Level Rise: Evaluating the Role of Vegetation, Sediment, and Upland Habitat in Marsh Resiliency. PLoS ONE 9(2).

Schupp C. 2013. Assateague Island National Seashore: geologic resources inventory report. Natural resource report NPS/NRSS/GRD/NRR—2013/708. National Park Service, Fort Collins, Colorado.

Short F.T., Kosten S., Morgan P.A., Malone S., Moore G.E. 2016. Impacts of climate change on submerged and emergent wetland plants. Aquatic Botany 135:3-17.

Simard M., Zhang K., Rivera-Monroy V.H., Ross M.S., Ruiz P.L., Castañeda-Moya E., Twilley R.R., Rodriquez E. 2006. Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data. Photogrammetric Engineering & Remote Sensing. 72 (3): 299–311.

Stabenau E., Engel V., Sadle J., Pearlstine L. 2011. Sea-level rise: Observations, impacts, and proactive measures in Everglades National Park. Park Science 28:26-30.

Stocker T.F., Qin D., Plattner G.-K, Tignor M., Allen S.K., Boschung J., Nauels A.,. Xia Y, Bex V., Midgley P.M.. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, 2013, Cambridge University Press, Cambridge, United Kingdom and New York, NY, US.

Thieler E.R. and Hammar-Klose E.S. 1999. National assessment of coastal vulnerability to sea-level rise: Preliminary results for the U.S. Atlantic coast. Open- File Report 99-593. U.S. Geological Survey, Reston, Virginia, USA. Available from https://pubs.usgs.gov/dds/dds68/reports/eastrep.pdf

Wanless H.R., Parkinson R.W., Tedesco L.P. 1997. Sea level control on stability of Everglades wetlands. In: Davis S.M., and Ogden J.C, editors. Everglades: The Ecosystem and Its Restoration. CRC Press.

Yao Q., and Liu K. 2017. Dynamics of marsh-mangrove ecotone since the mid-Holocene: A palynological study of mangrove encroachment and sea level rise in the Shark River Estuary, Florida. PLoS ONE 12(3).

Tables and Figures

Table 1. Landsat Imagery summary table.

	Satellite	Date	Path	Row
Acadia	Landsat 5	6/12/1984	11	29
	Landsat 8	8/23/2016	11	29
Assateague	Landsat 5	7/3/1984	14	33
	Landsat 8	7/11/1984	14	33

Table 2. Acadia National Park Overall Change

IPCC Projection	Inundated Area (KM^2)	Non Inundated Area (KM^2)	Total Area (KM^2)	Change in Inundation	% Change
RCP 2.6	1.17	213.56	214.74	N/A	N/A
RCP 4.5	1.21	213.53	214.74	0.04	3.42
RCP 8.5	1.36	213.38	214.74	0.19	15.7

Table 3. Assateague Island National Seashore Overall Change

IPCC Projection	Inundated Area (KM^2)	Non Inundated Area (KM^2)	Total Area (KM^2)	Change in Inundation	% Change
RCP 2.6	32.48	23.03	55.51	N/A	N/A
RCP 4.5	34.02	21.49	55.51	1.54	4.74
RCP 8.5	37.11	18.40	55.51	4.63	14.25

Table 4. Everglades National Park Overall Change

IPCC Projection	Inundated Area (KM^2)	Non Inundated Area (KM^2)	Total Area (KM^2)	Change in Inundation	% Change
RCP 2.6	306.59	229.60	536.19	N/A	N/A
RCP 4.5	334.51	201.67	536.19	27.92	9.11
RCP 8.5	366.47	169.72	536.19	31.96	10.42

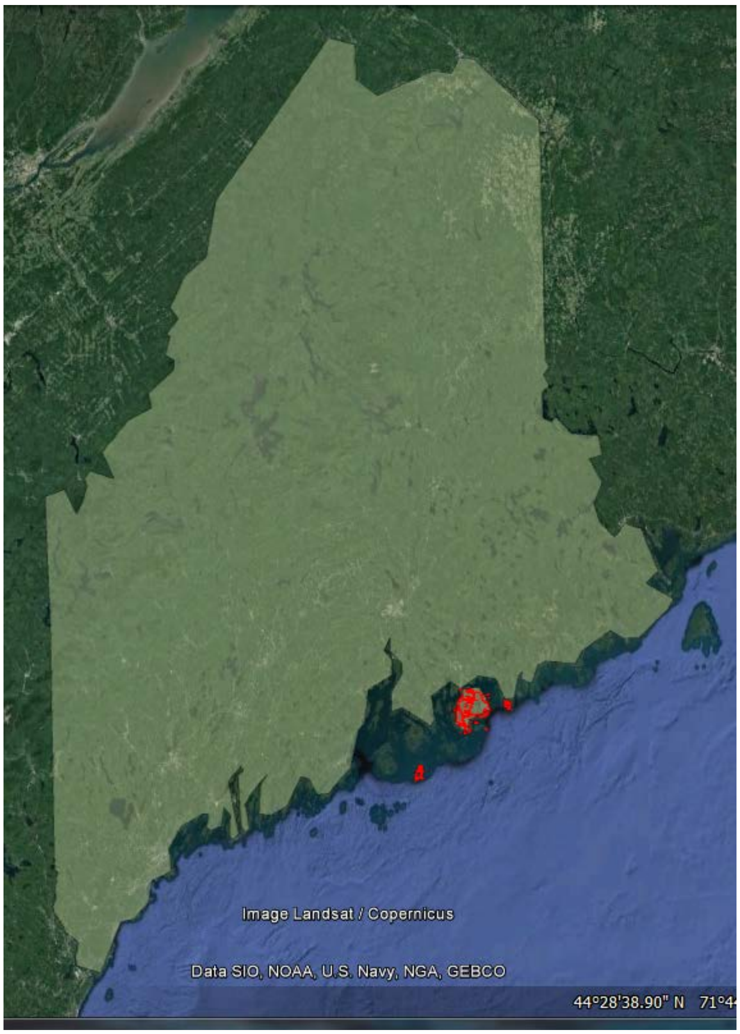


Figure 1. Location of Acadia National Park in south-central Maine. The park boundaries are outlined in red.

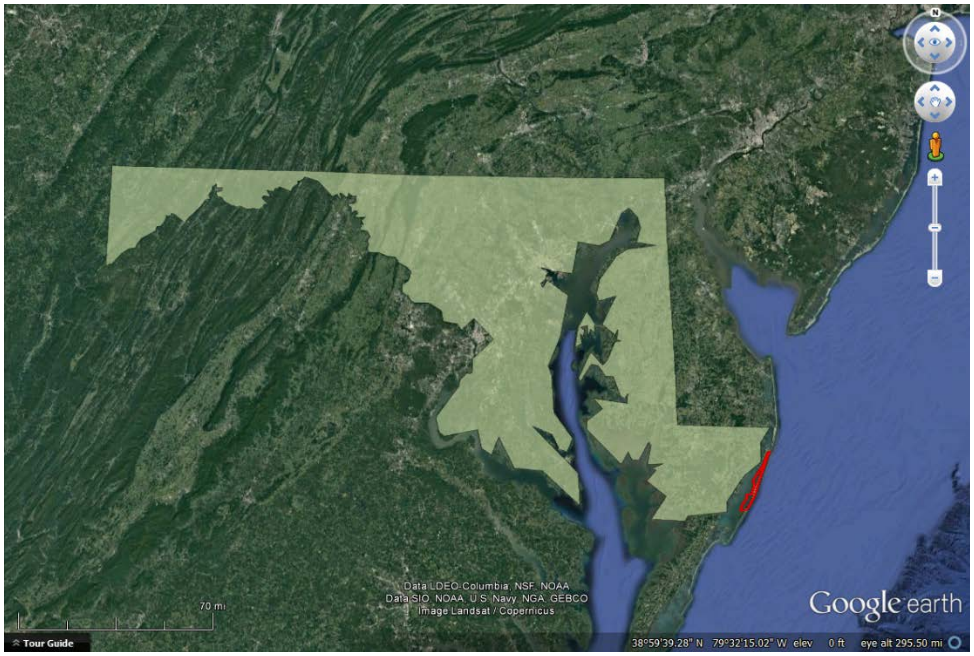


Figure 2. Location of Assateague Island National Seashore in eastern Maryland. The park boundaries are outlined in red.

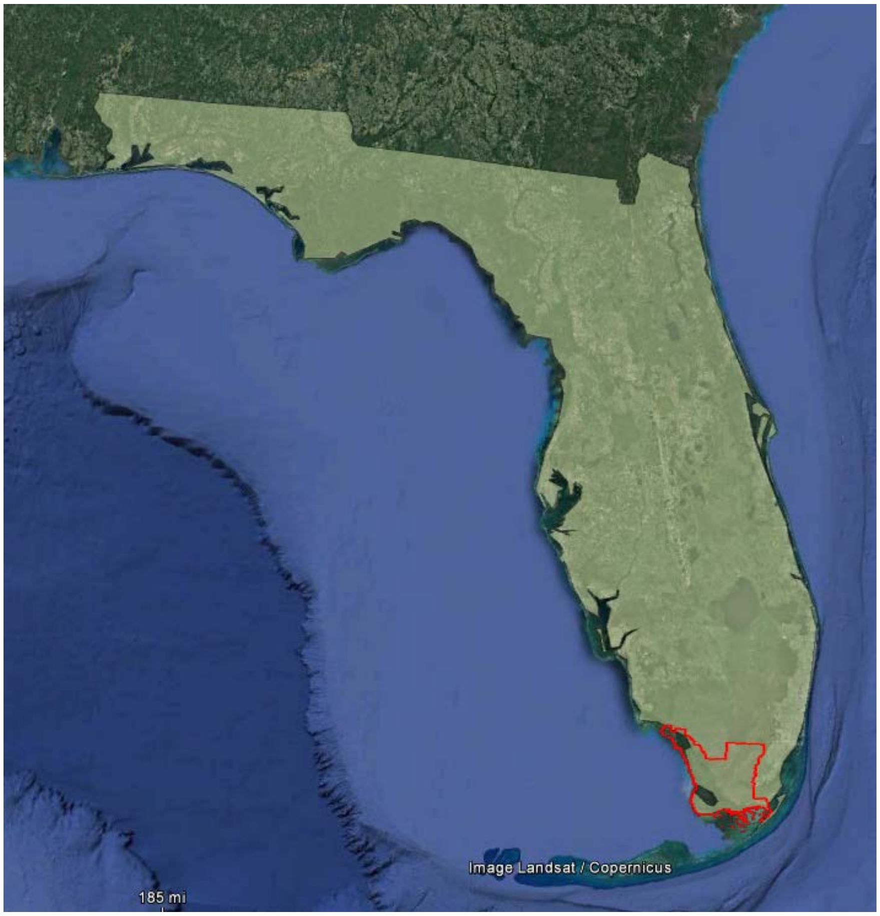


Figure 3. Location of Everglades National Park in southern Florida. The park boundaries are outlined in red.

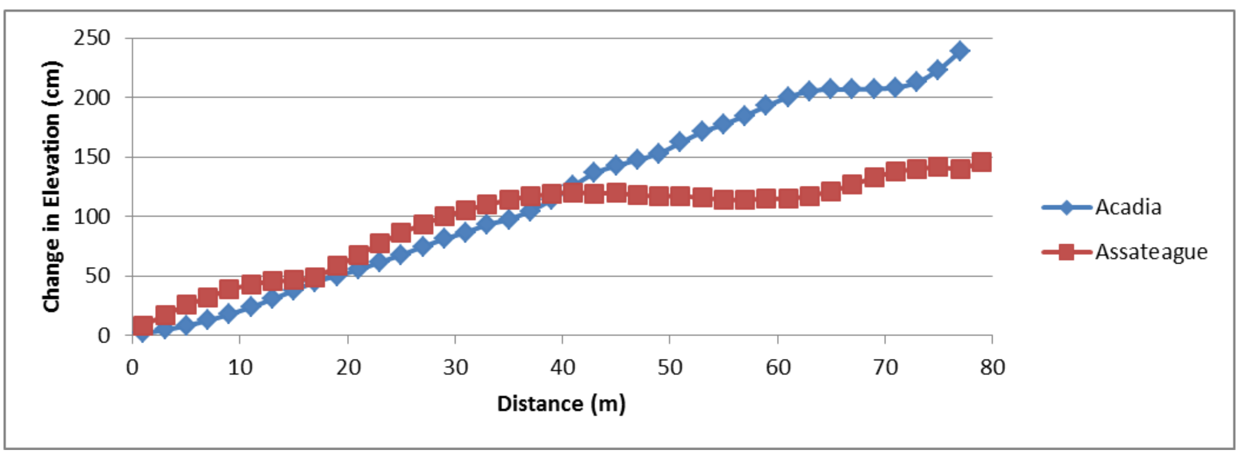
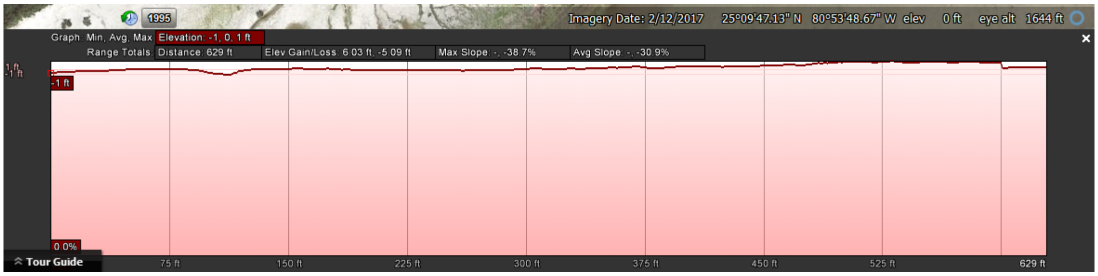


Figure 4. Beach profiles of Sand Beach at Acadia National Park and South Ocean Beach at Assateague Island National Seashore.



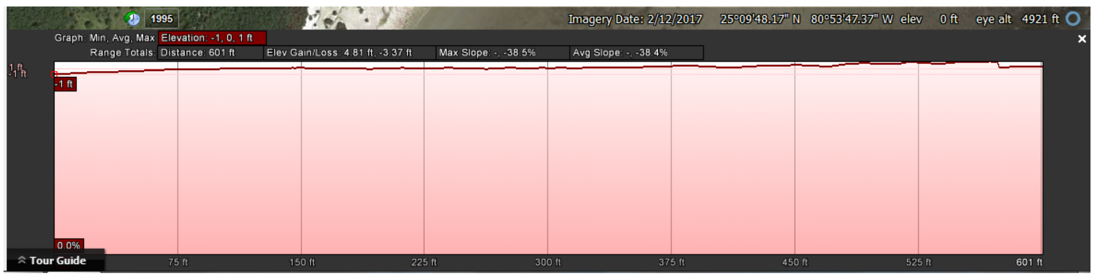


Figure 5. Digital beach profiles of Transect 1 and 2 at Snake Bight Channel in Everglades National Park. Made using Google Earth.

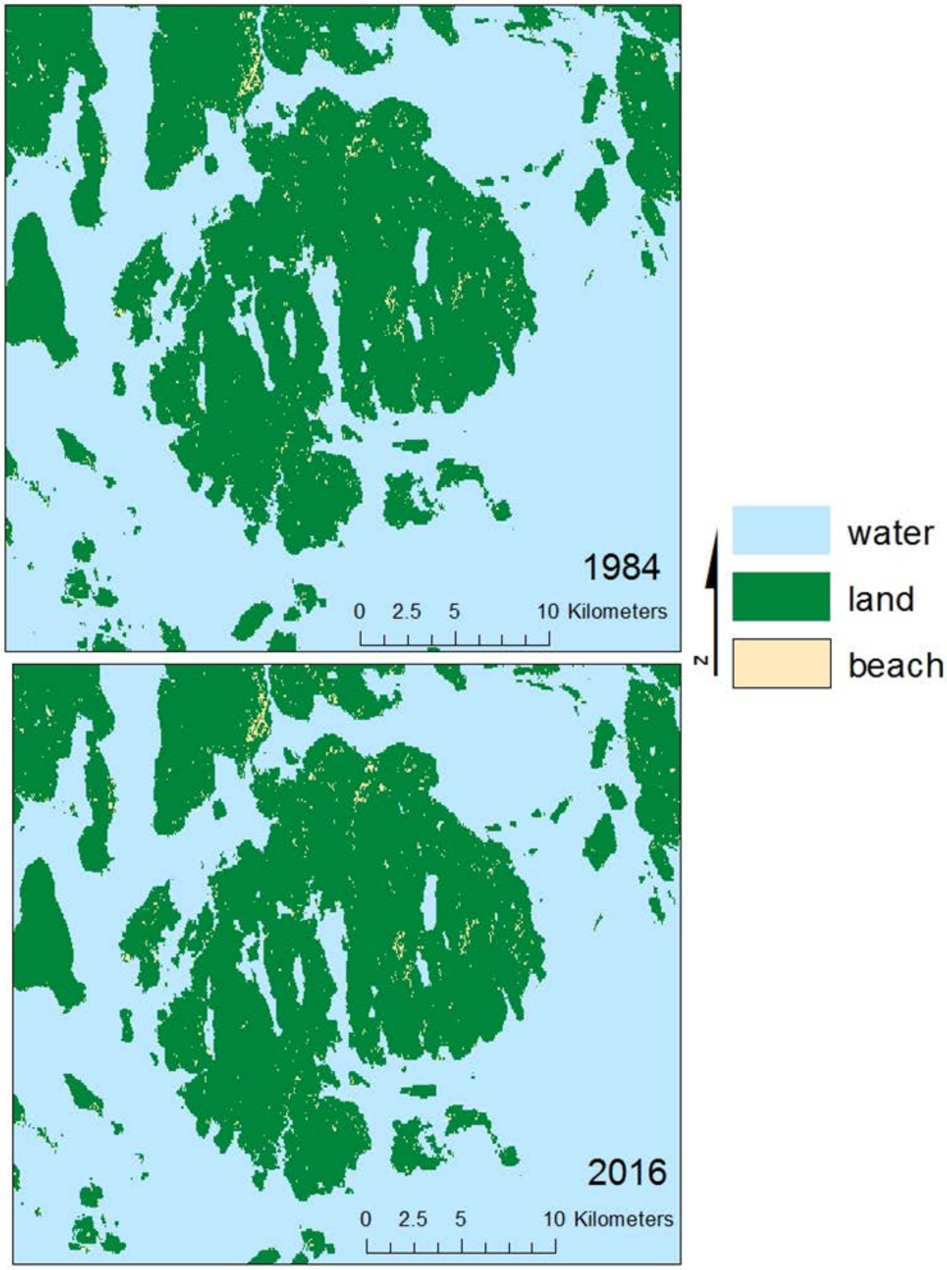


Figure 6. Acadia National Park historical inundation levels from 1984 to 2016.

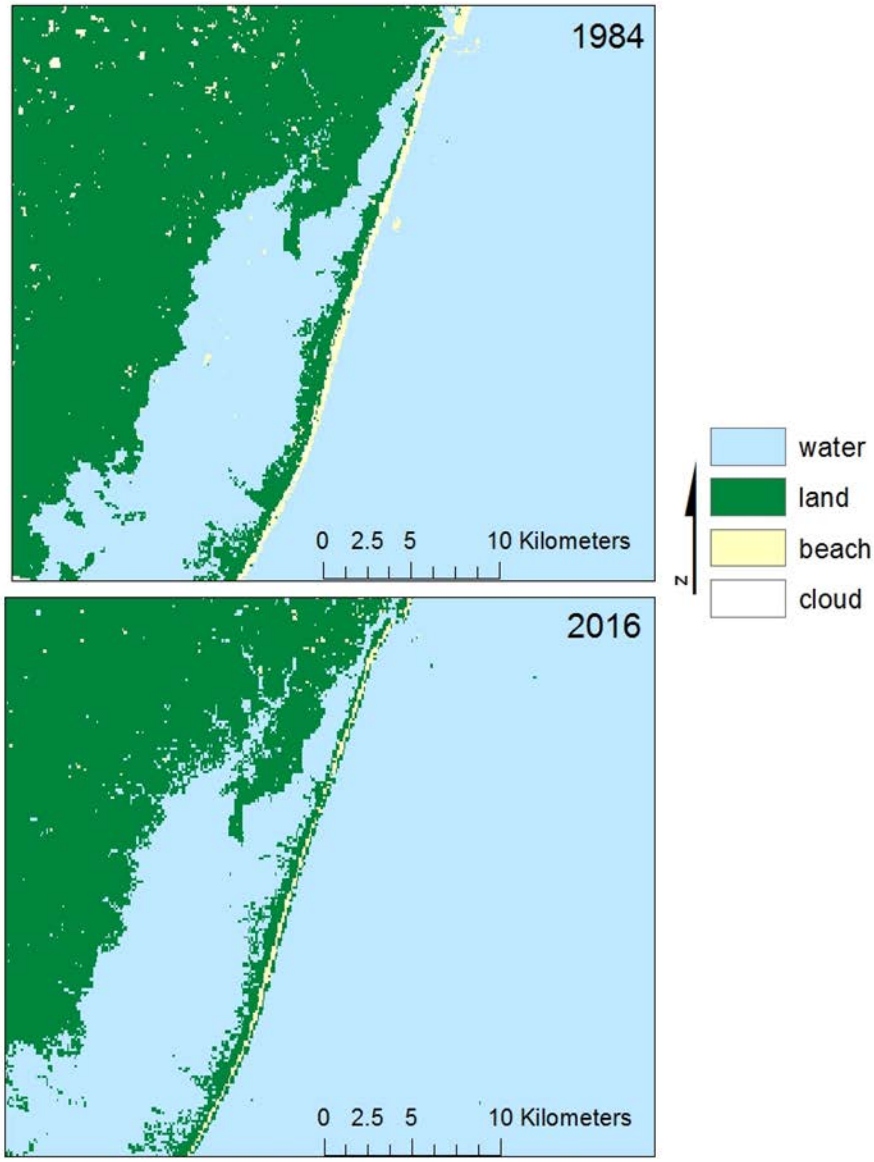


Figure 7. Assateague Island National Seashore historical inundation levels from 1984 to 2016.

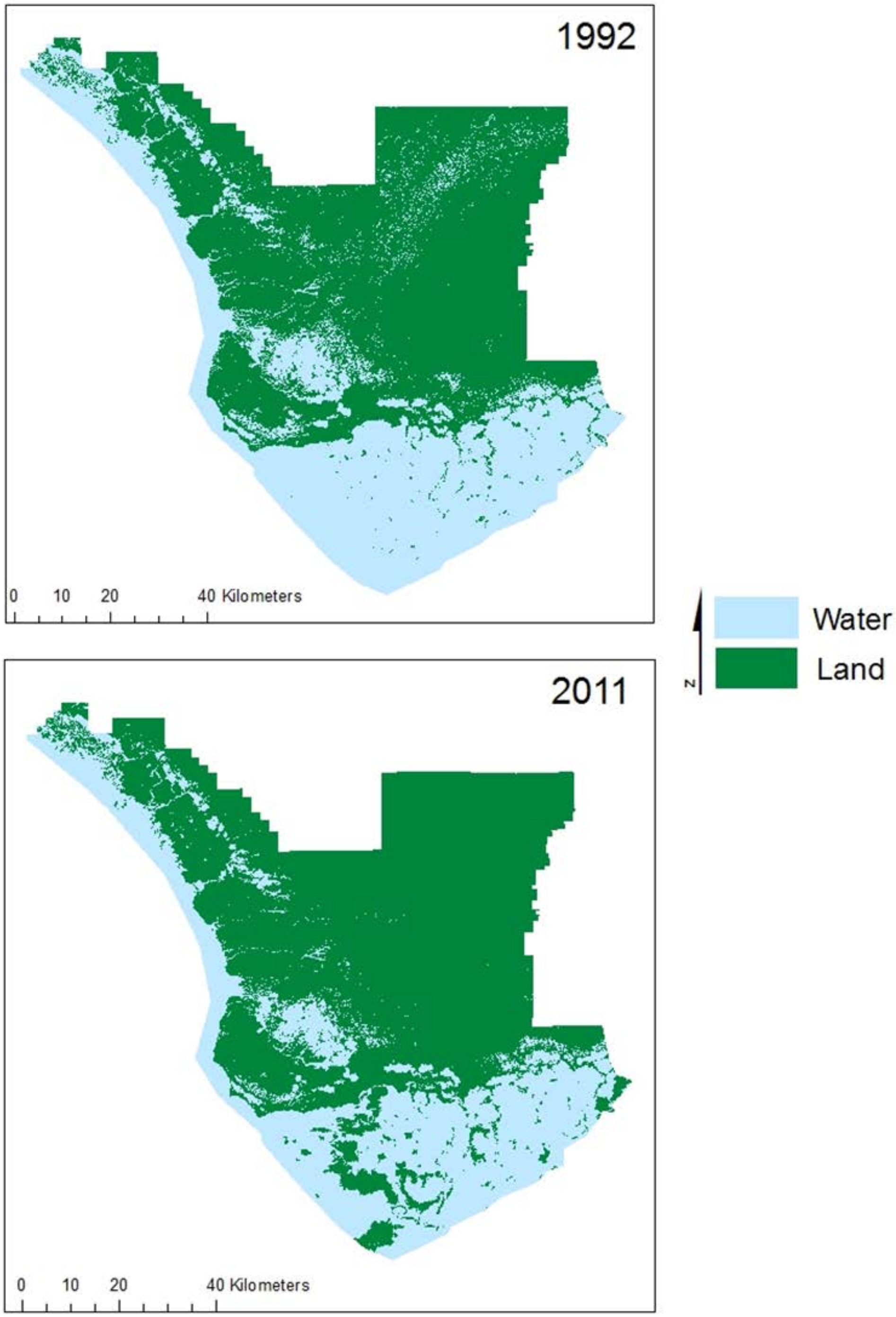


Figure 8. Everglades National Park historical inundation levels from 1992 to 2011.

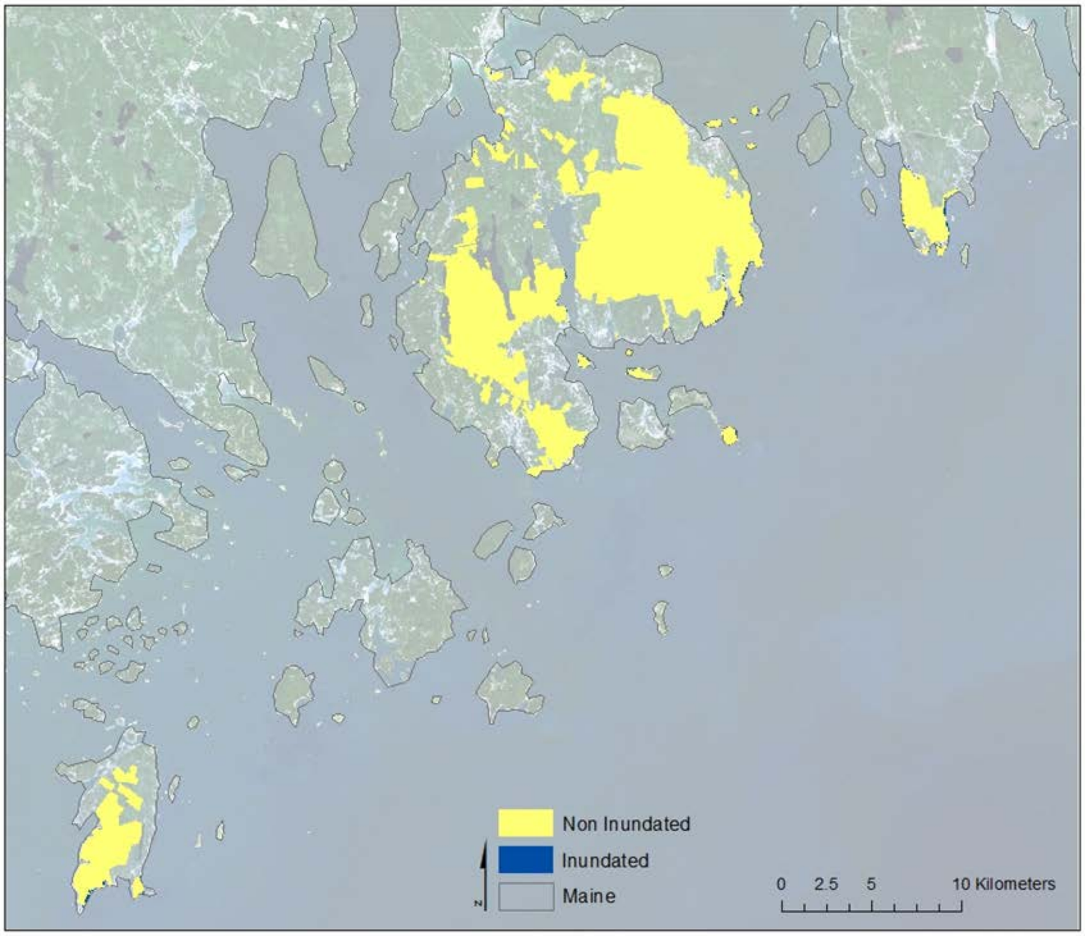


Figure 9. Acadia National Park showing inundation levels under the IPCC RCP2.6 projection.

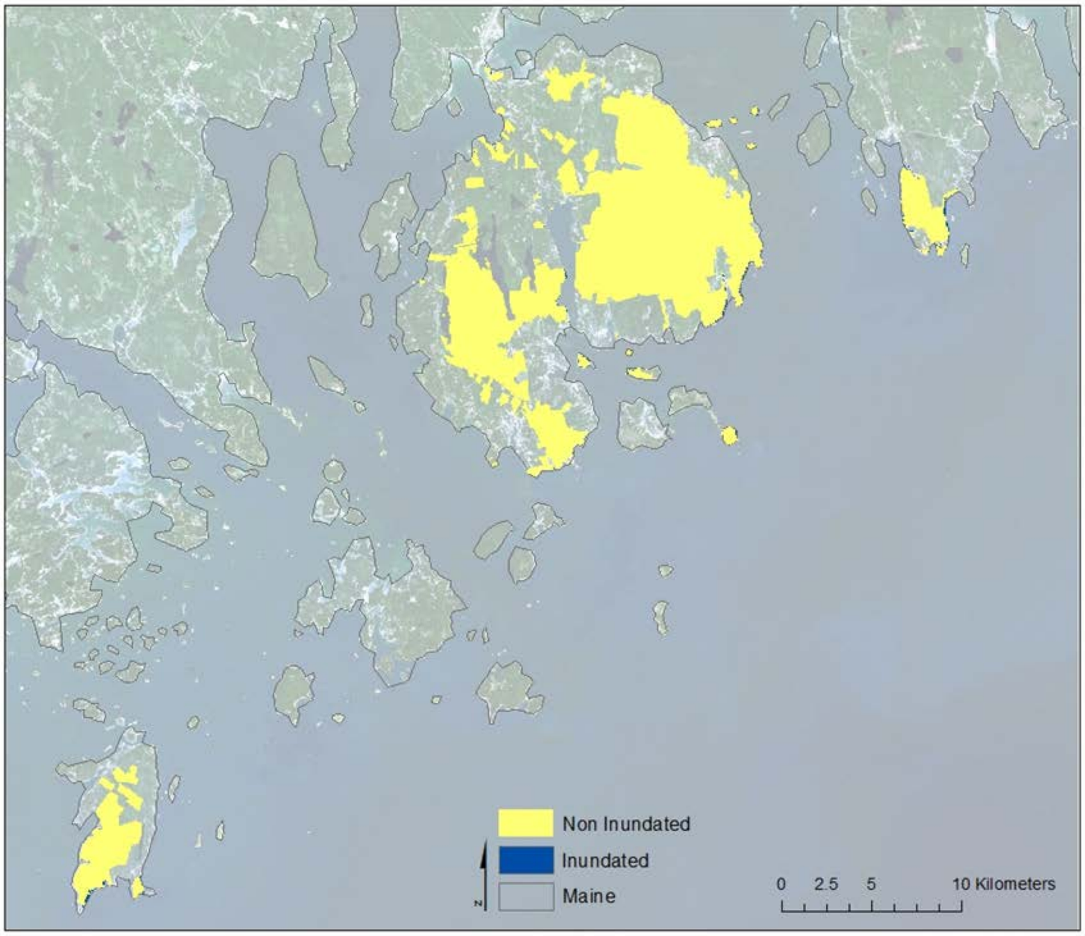


Figure 10. Acadia National Park showing inundation levels under the IPCC RCP4.5 projection

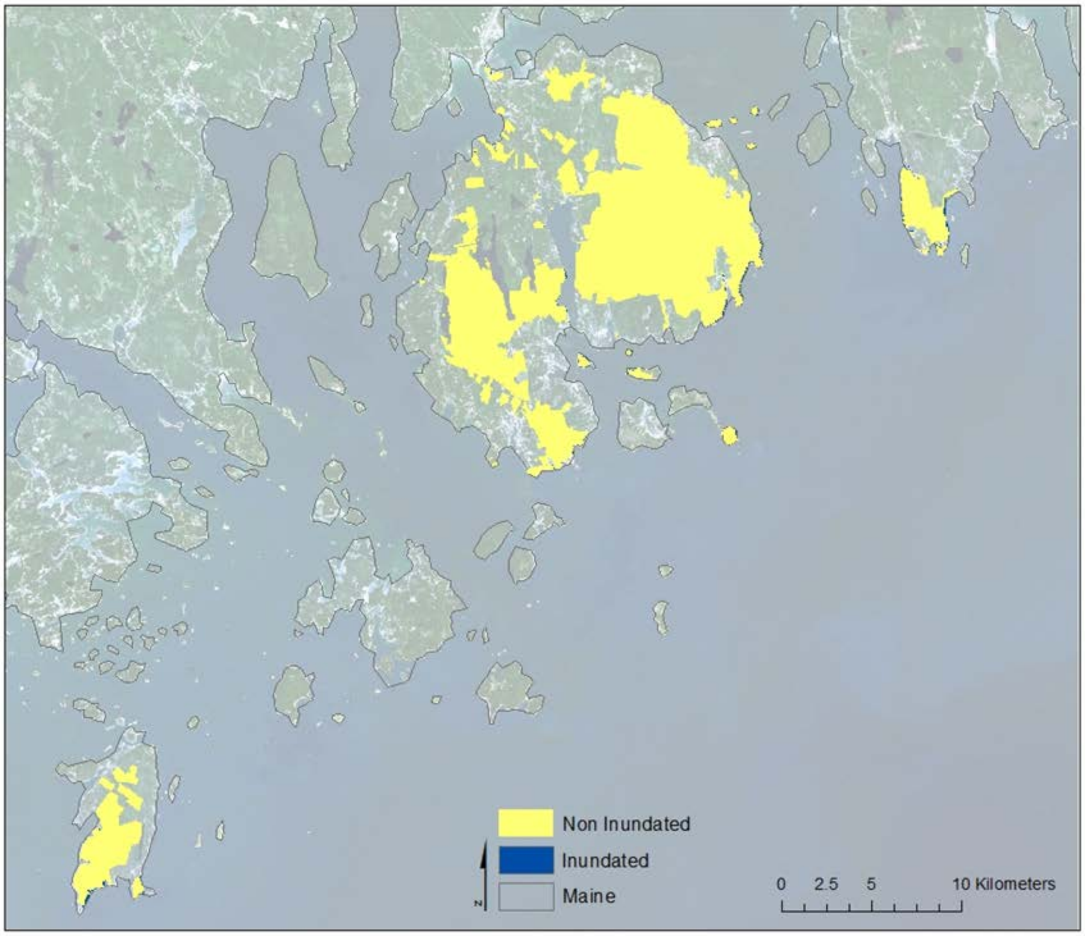


Figure 11. Acadia National Park showing inundation levels under the IPCC RCP8.5 projection.

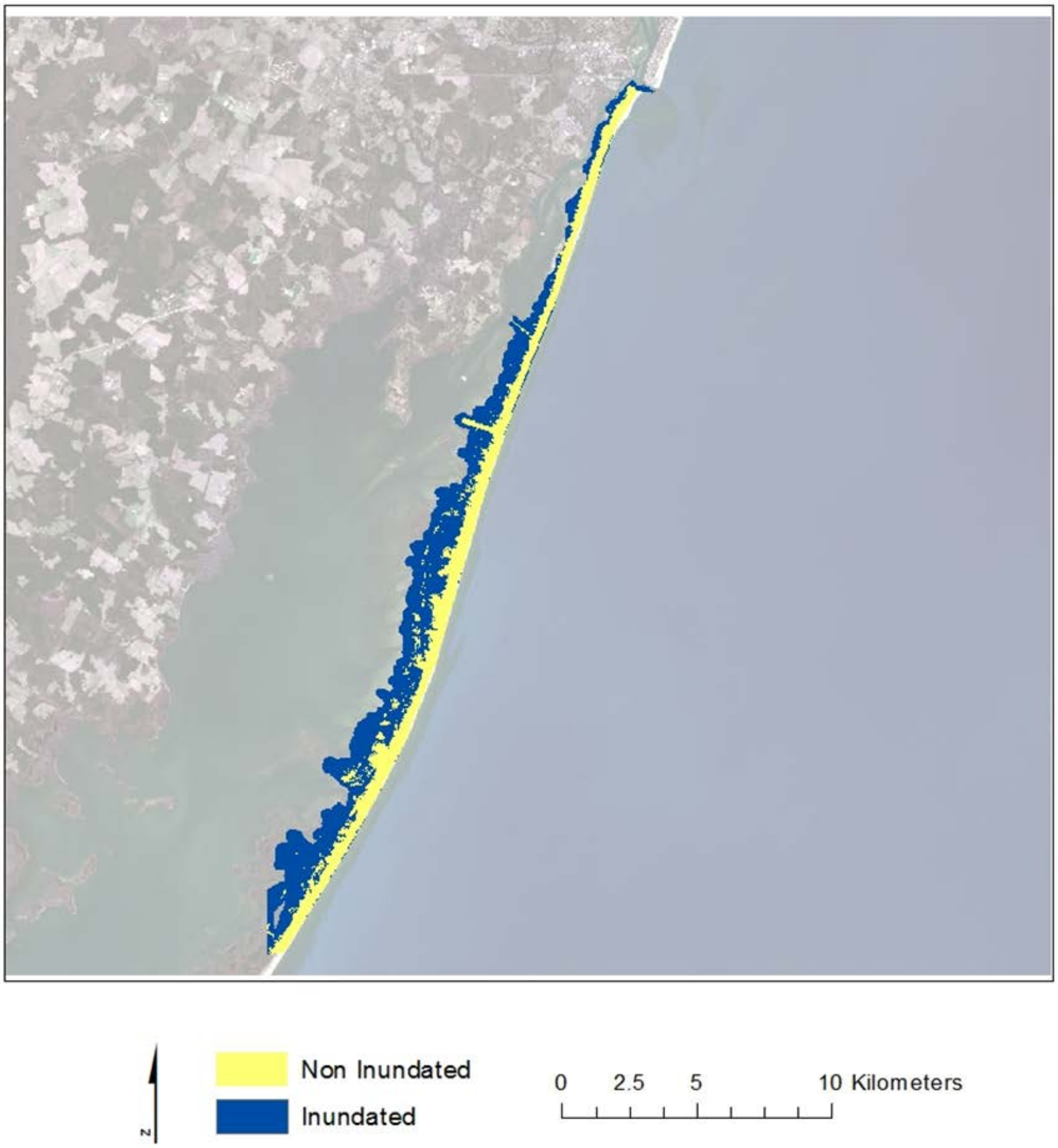


Figure 12. Assateague Island National Seashore inundation levels under IPCC RCP2.6 scenario

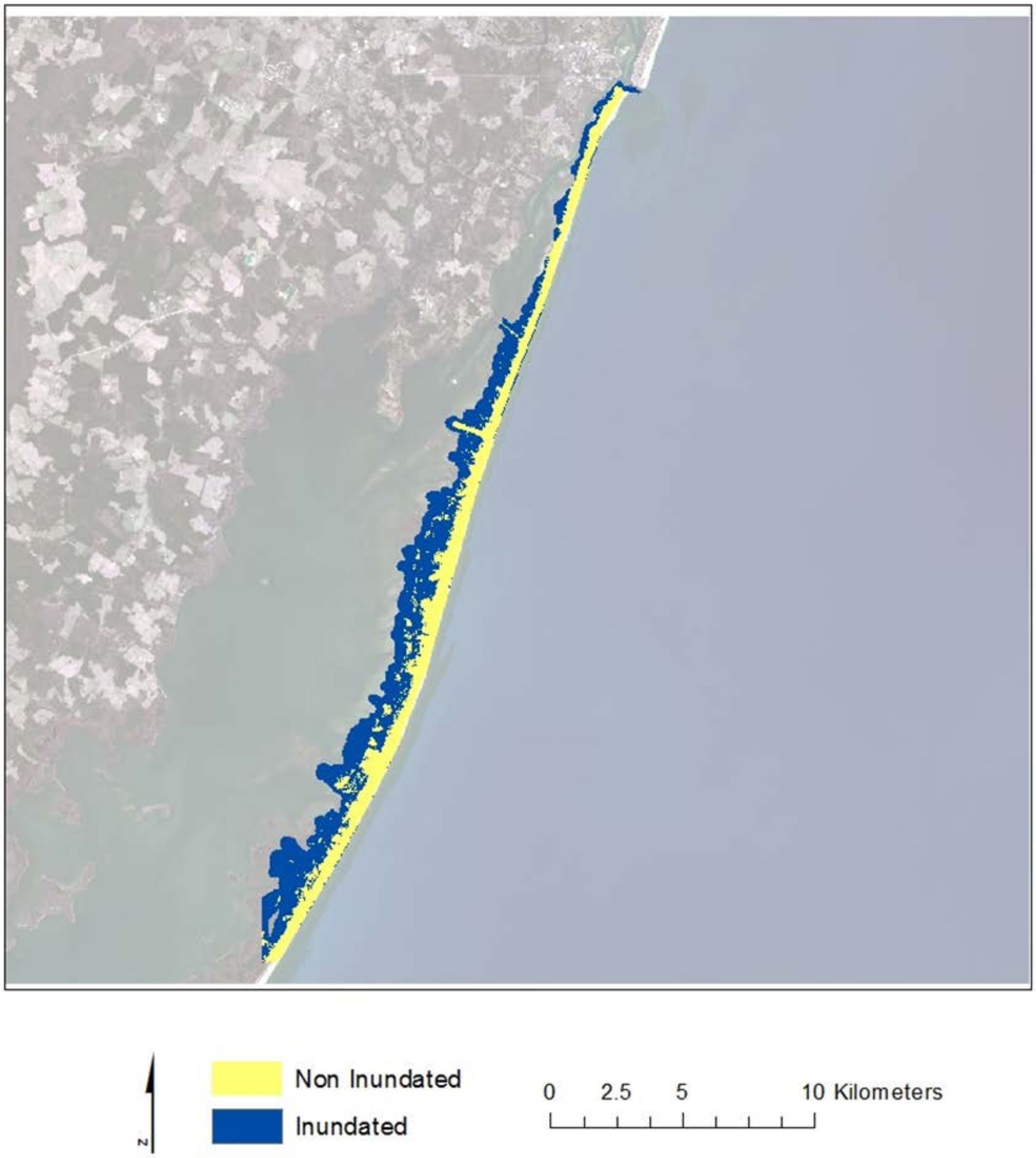


Figure 13. Assateague Island National Seashore inundation levels under IPCC RCP4.5 scenario.

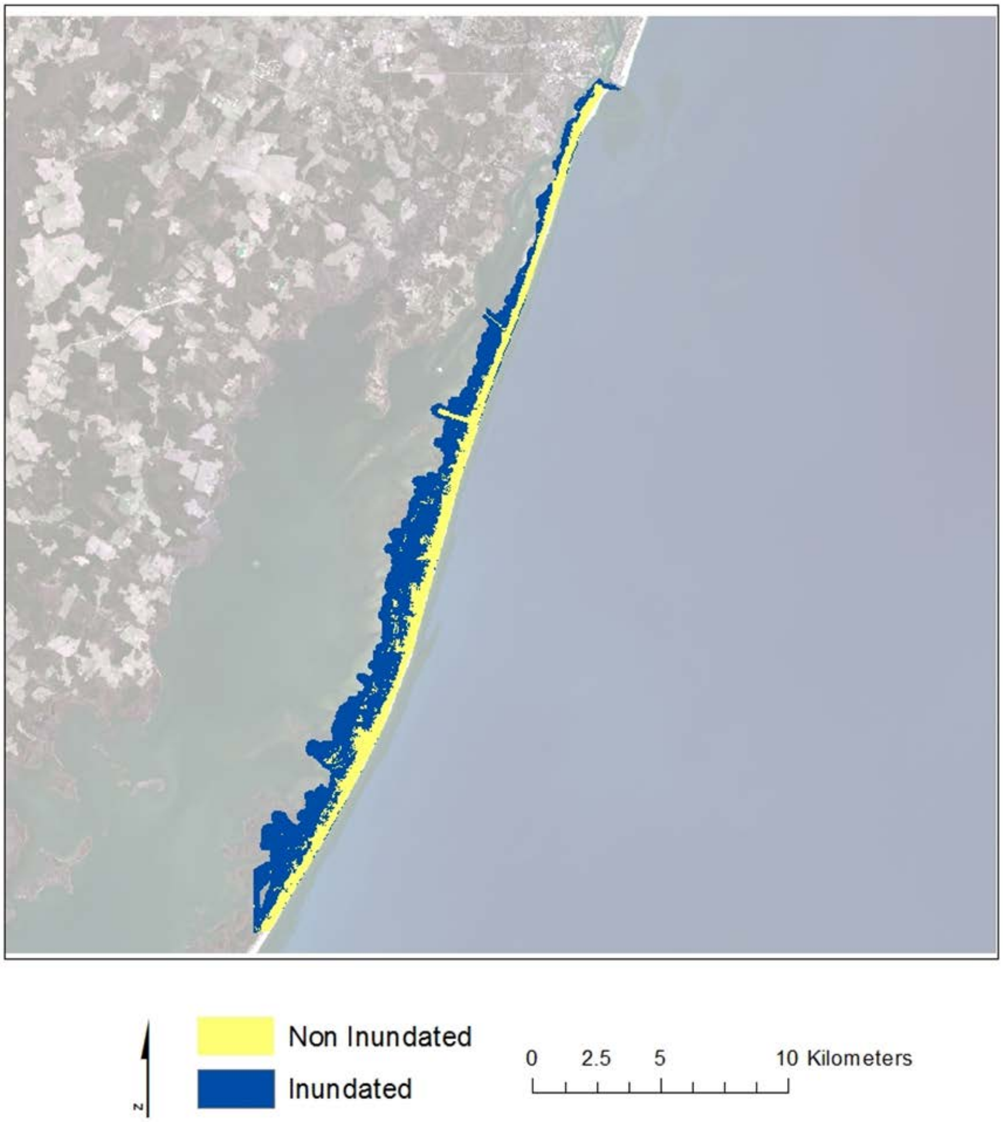


Figure 14. Assateague Island National Seashore inundation levels under IPCC RCP8.5 scenario.

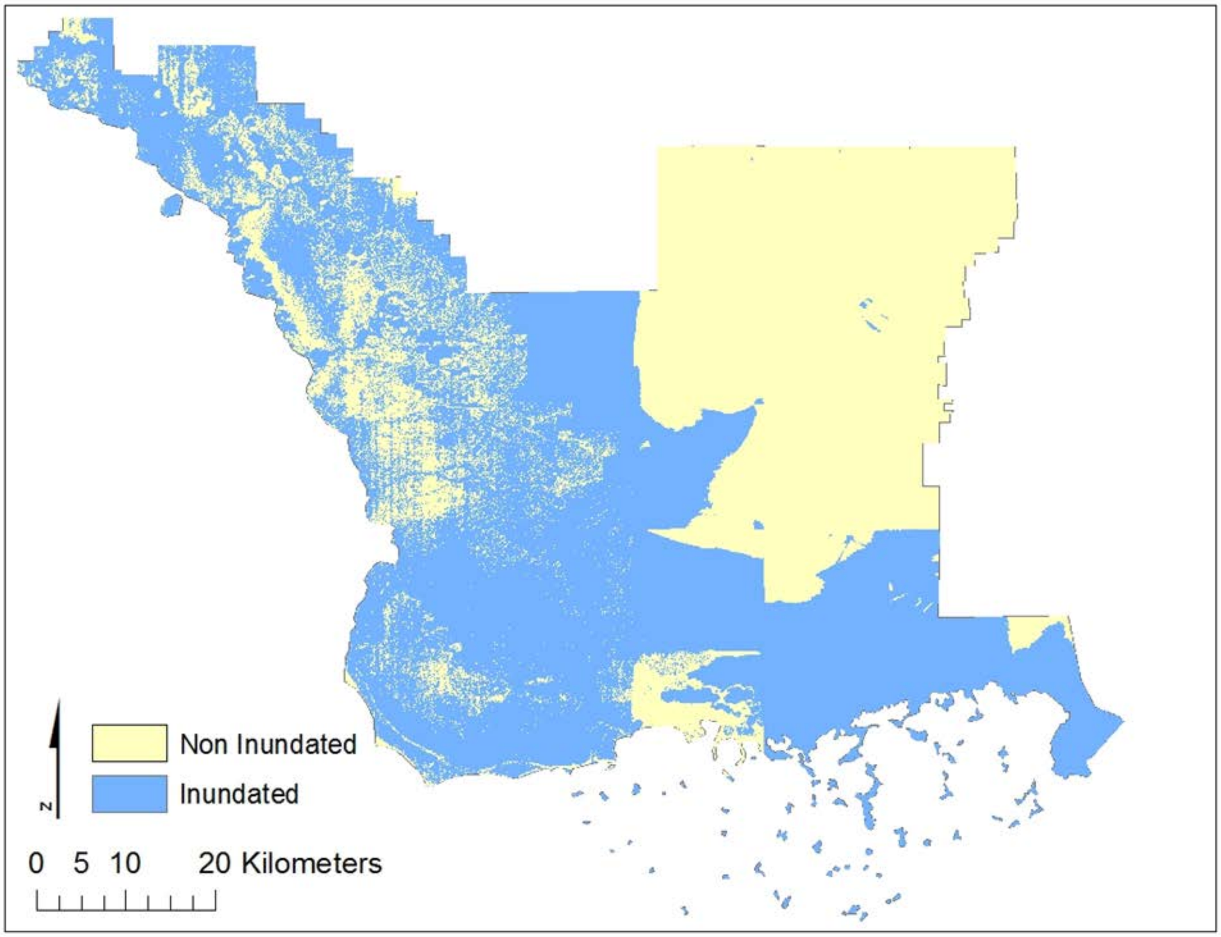


Figure 15. Everglades National Park inundation levels under the IPCC RCP2.6 scenario.

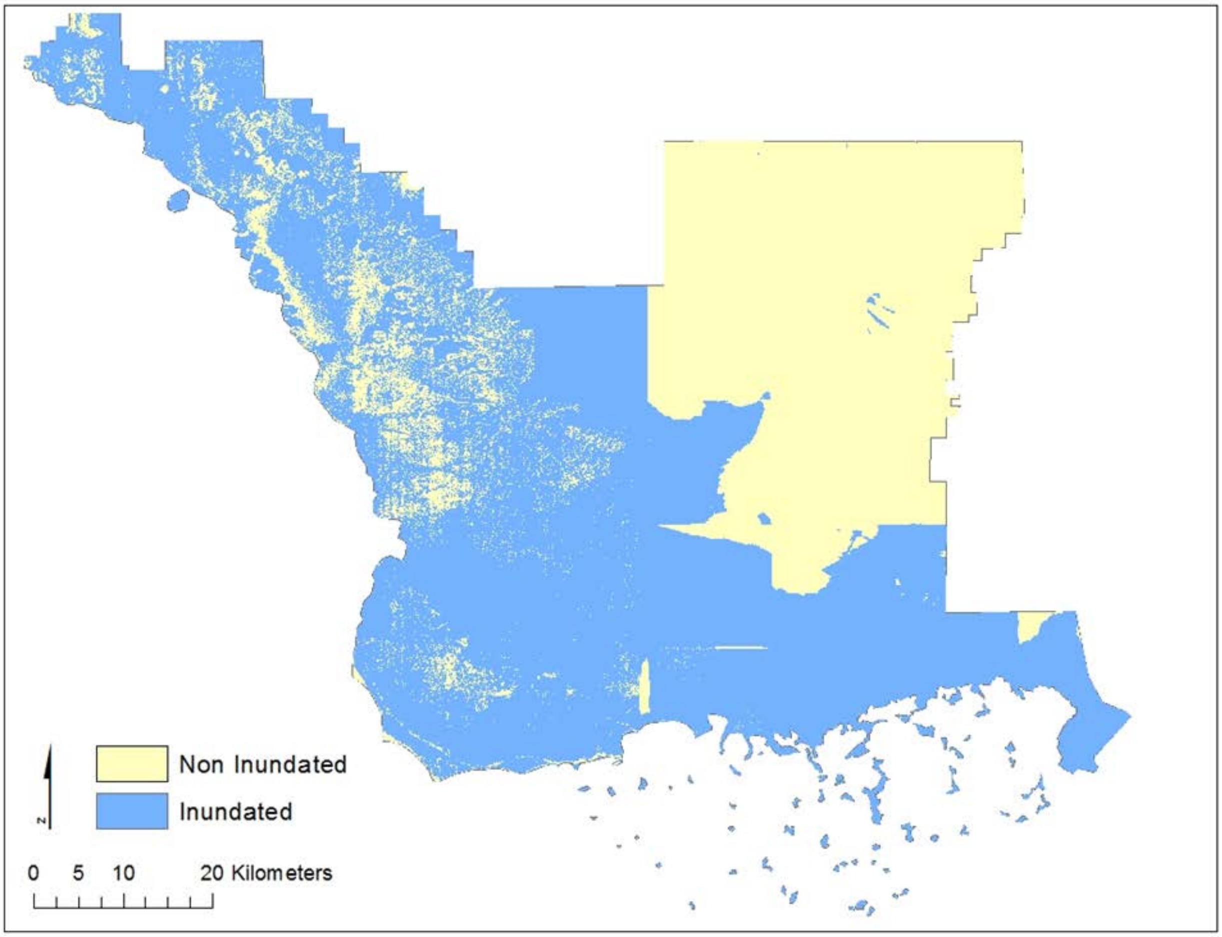


Figure 16. Everglades National Park inundation levels under the IPCC RCP4.5 scenario.

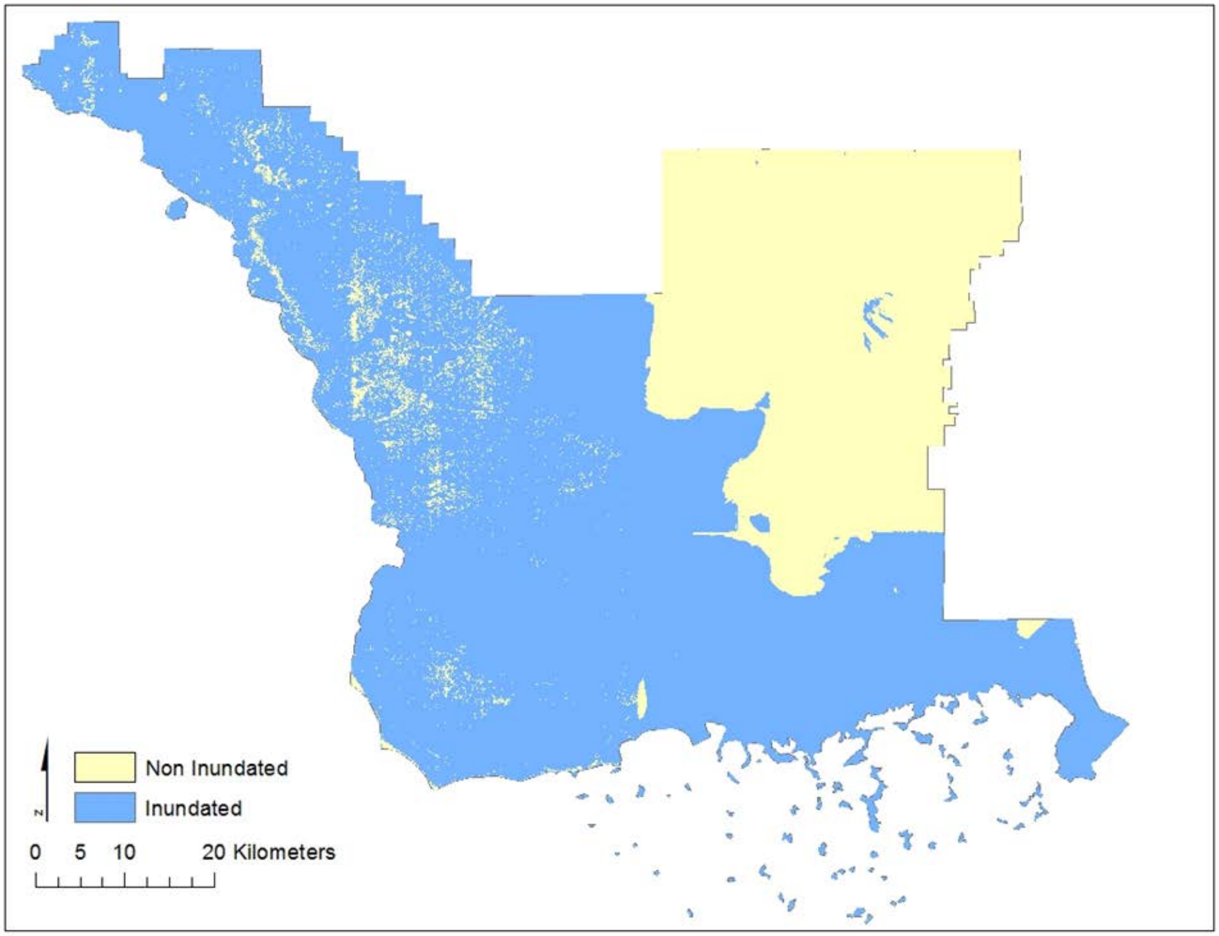


Figure 17. Everglades National Park inundation levels under the IPCC RCP8.5 scenario.