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Life without the Beach: Projected Sea Level Rise and its Impact on Barrier Islands Along the East Coast, USA

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As climate change is becoming a global issue, the impact of sea level rise is increasingly becoming a threat to humans, wildlife, infrastructure, and ecosystems. To evaluate the effects of sea level rise on barrier islands and coastal regions, we studied future projections of sea level rise at Ocean City and Assateague Island, Maryland. We hypothesize that the sea levels at Assateague and Ocean City will have different beach profiles, and will show different levels of flooding through the Representative Concentration Pathways (RCP) simulations. We measured beach profiles at four locations, two at Ocean City and two at Assateague Island, to view the current beach profiles and found that Ocean City reveals a smaller average change in elevation compared to Assateague. We also used a LiDAR Digital Elevation Model (DEM) of Ocean City and Assateague Island to run RCP 2.6, RCP 4.5, and RCP 8.5 simulations using GIS to represent the Intergovernmental Panel on Climate Change (IPCC) projected sea level rise for the year 2100. We found that Ocean City has higher predicted percentages of flooded land but smaller areas of flooded land compared to Assateague. These results indicate that significant areas of both Ocean City and Assateague Island will be flooded by 2100 regardless of which RCP simulation might be true. However, it is projected that the RCP 2.6 simulation is an underestimation of potential flooding and the future will more closely resemble the RCP 8.5 simulation if drastic precautions are not taken now. This will severely impact ecosystems, economies, and human life.

Keywords
Sea level rise, Assateague Island, Ocean City, beach profiles, RCP analysis

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Environmental Indicators and Impact Assessment | Environmental Sciences | Water Resource Management

Comments
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Honor Code

I affirm that I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation of the Honor Code.
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Abstract

As climate change is becoming a global issue, the impact of sea level rise is increasingly becoming a threat to humans, wildlife, infrastructure, and ecosystems. To evaluate the effects of sea level rise on barrier islands and coastal regions, we studied future projections of sea level rise at Ocean City and Assateague Island, Maryland. We hypothesize that the sea levels at Assateague and Ocean City will have different beach profiles, and will show different levels of flooding through the Representative Concentration Pathways (RCP) simulations. We measured beach profiles at four locations, two at Ocean City and two at Assateague Island, to view the current beach profiles and found that Ocean City reveals a smaller average change in elevation compared to Assateague. We also used a LiDAR Digital Elevation Model (DEM) of Ocean City and Assateague Island to run RCP 2.6, RCP 4.5, and RCP 8.5 simulations using GIS to represent the Intergovernmental Panel on Climate Change (IPCC) projected sea level rise for the year 2100. We found that Ocean City has higher predicted percentages of flooded land but smaller areas of flooded land compared to Assateague. These results indicate that significant areas of both Ocean City and Assateague Island will be flooded by 2100 regardless of which RCP simulation might be true. However, it is projected that the RCP 2.6 simulation is an underestimation of potential flooding and the future will more closely resemble the RCP 8.5 simulation if drastic precautions are not taken now. This will severely impact ecosystems, economies, and human life.

Key Terms: Sea level rise; climate change; Assateague Island, MD; Ocean City, MD; beach profile; RCP analysis; IPCC

Introduction

Sea level rise is a pressing conflict for coastal communities, organisms living in intertidal and marine zones, and the general aesthetics of beaches. Barrier islands are especially susceptible to sea level rise because of the nature of their thin size and shape compared to coastlines that are connected to the mainland (Passeri et al., 2018). One problem that has been predicted to affect barrier islands as sea level continues to rise from climate change is an increase in storm surges and in storm surge intensity (Passeri et al., 2018). A past study performed by Passeri et. al (2018) discusses how rising sea levels have affected barrier islands because they are seeing an increase in inundation, and an increase in the duration and spatial characteristics of overwash. Global temperature rises due to climate change causes an increase in storm frequency and intensity, according to past studies (Munger and Kraus, 2010). These storms not only lead to more inundation and overwash, but will cause extreme wind speeds, flooding, wave attacks on the upper beach areas and infrastructure, and erosion, further damaging beaches and barrier islands (Munger and Kraus, 2010). Barrier islands are even more at risk from these problems because of their size, shape, and proximity to the mainland (Munger and Kraus, 2010). Another study by Houser et al. (2018) mentions that smaller sand dunes are more susceptible to erosion in the wake of storms, and that barrier islands have been found to have smaller sand dunes in most places when compared to mainland shores. Therefore, as storm intensity increases due to sea level rise and climate change, beaches along barrier islands will erode at a faster rate, making them more susceptible to flooding from sea level rise (Houser et al., 2018).

Hazardous weather events and anthropogenic influences, as well as sea level rise, impacts beach profiles across barrier islands (Ritter et al.). As global sea level rises as a result of climate change and storm events become more frequent and intense, alterations to the profile of barrier islands will also occur more frequently (NPS, 2015). In a study by Jones (2014), the research demonstrates that extreme weather events are drastically morphing landscapes and beach profiles, and because of the relationship between tidal range, wave action, sediment supply, sea level trends, climatology, and weather events, it is predicted that beach profiles are going to change as an increased rate . Another study conducted by Deaton et al. (2017) observed the effects of sea level rise on back barrier environments and salt marshes . Backbarrier environments are the areas on barrier islands that face the mainland, sometimes referred to the bayside of barrier islands (Deaton et al., 2017). They discovered that as sea level continues to rise, more salt water has intruded into the marshes and backbarrier areas through inundation, and land along the bayside has been lost (Deaton et al., 2017). This is concerning for barrier islands because it means that land is being lost both on the ocean-facing sides as well as the bayside of barrier islands (Deaton et al., 2017).

Barrier islands typically form when sand accumulates off the coast of a mainland, or when inland dunes break away from the mainland because of high water levels on the coast (Ritter et al., 2011). These unique landforms are very dynamic because of their close proximity to the mainland as well as their coastal ecosystem interacting with the ocean (Ritter et al., 2011). Assateague Island is a barrier island along the coasts of Maryland and Virginia. It was once connected to Fenwick Island, where Ocean City exists today, but a storm in 1933 created an inlet between the two areas (NPS, 2015). In 1965 the Maryland side of Assateague, as well as the surrounding waters, was deemed a National Seashore called Assateague State Park (NPS, 2015). The National Park Service used a bridge connecting the Maryland side with the Virginia section of the island, called Chincoteague National Wildlife Refuge, to protect the entirety of the Assateague Barrier Islands (NPS, 2015). Primarily, Assateague Island is a protected and undeveloped park that is open to the public, but requires visitor fees and entry passes for the millions of visitors each year (NPS, 2019). These areas are both prone to environmental changes, but analysis of the past 1,000-2,000 years has revealed that the barrier island Parramore, in Virginia, which is part of the National Park, has alternated between landward migration, erosion and seaward progradation (Raf et. al 2018). Additionally, storms also contribute to a process known as “island rollover”, which is continuing to shape Assateague Island and Ocean City’s beach profiles (NPS, 2015; Ritter et al.2011). This process of island rollover occurs when flood waters from sea level rise and storms impact the sand content on the island by moving the deposits to marshes nearby (NPS, 2015; Ritter et al., 2011). This process causes changes to the profile of the beach by causing it to narrow (NPS, 2015; Ritter et al., 2011).

The purpose of this study is to evaluate the impact of sea level rise on Assateague Island and Ocean City to compare the difference in beach profiles between an undeveloped and a developed barrier island beach ecosystem. We will examine trends of sea level change and beach profiles, as well as make future projections of sea level change for the year 2100 and how that will impact the beach profiles. Our research questions is: what are the possible outcomes of future sea level rise? Our objectives include determining how much the sea levels have already risen, and how they are projected to rise based on a Representative Concentration Pathway (RCP) analysis for the year 2100 using the Intergovernmental Panel on Climate Change (IPCC) predictions for sea level rise. We will also consider the connections of how these changes could impact other biotic and abiotic factors in coastal environments, as well as cultural implications. The rationale for this project is that beaches are incredibly important ecosystems and cultural locations. The future of beaches is incredibly important, not only for recreation, but also for the economy, including tourism and the coastal fishing industry in these areas (Houston, 2008). Future generations may not get the opportunity to bask in the sun on a sandy beach, to play frisbee on a coast as a beautiful sunset paints the clouds lingering above, or to build a sand castle on a beach with enough room without a wave crashing over it. In our own short lifetimes, we have noticed the shape of our local beaches change over the years, causing us to consider how a national shoreline or developed beach on a barrier island, such as Assateague Island and Ocean City, is affected in similar or different ways. We hypothesize that the sea levels at Assateague and Ocean City will have different beach profiles, and will show different levels of flooding through the RCP simulations. We expect that both areas will be severely flooded in the RCP 8.5 simulation.

Methods

Beach Profiling Procedure

We collected beach elevations of four locations, two in Ocean City, MD, and two at Assateague, MD (Figure 1). The two profiles recorded at Ocean City labeled as OC 1 z938°19’28.9632” N 75°5’9.3876” W) and OC 2 (38°19’37.3296” N 75°05’5.5258” W) while the two at Assateague as labeled as AS 1 (38°11’25.0044” N 75°9’26.2075” W) and AS 2

(38°12’12.726” N 75°9’6.9850” W) (Figure 1b). The beach profiles in Ocean City were measured on February 23, 2019 between 1 and 2 PM and the profiles at Assateague were measured the same day between 3 and 4 PM. Low tide on this day at Ocean City, MD was at 5:00 PM and was 4:37 PM at Assateague, MD. For each beach profile measurement, we created a transect that started at the highest point of the berm and extended as far into the swash zone as tide permitted. Starting at the berm, or position 1, meter stick poles were used to measure the change in elevation using two meter intervals along the transect (Figure 2). To measure the change in elevation, a person would stand at positions one and two and hold her poles perpendicular to the ground (Figure 2). The person at position one would then position herself so that the middle line on her pole was level with the horizon, and at the same time record the difference from zero that the pole at position two was (Figure 2). These measurements were collected every two meters along the transects, with transects ranging between 76 m and 84 meters long. The daily high water mark (HWM) was also recorded for each transect. We then plotted the changes in elevation to show the beach profiles at each location and measure the average change in elevation (Table 1).

RCP Analysis Procedure

Separate from the beach profile data, we completed a Representative Concentration Pathways (RCP) analysis for both Ocean City, Maryland and Assateague Island. Using a LiDAR digital elevation model (DEM) of both Ocean City and Assateague, we created flood maps of the RCP 2.6, RCP 4.5, and RCP 8.5 future projections of sea level rise from predictions from the latest Intergovernmental Panel on Climate Change (IPCC) report for 2100 (Table 2). We used the raster calculator to calculate the amount of land that is flooded under each RCP simulation

(0.5, 1.0, or 1.5 m increase) based on current elevations. We then calculated the percent of flooded land for each RCP, as well as the area of land that would be covered by sea level under each RCP simulation.

Results

Beach Profile Analysis

The beach profiles at Ocean City had lower average changes in elevation compared to those of Assateague, with the beach profile at AS 1 having the largest average change in elevation, while the beach profile at OC 1 had the smallest average change in elevation (Table 1). OC 1 shows a relatively flat beach profile with a dip as the transect entered the swash zone, while the beach profile at OC 2 a few more dips and a more drastic negative change in elevation as the transect entered the swash zone compared to OC 1 (Figure 3). The beach profiles at Assateague Island showed a larger relief compared to the profiles at Ocean City, which were flatter in profile (Figure 3).

At Ocean City, there were multiple tire tracks that crisscrossed our transects for data collection, and at Assateague Island there were fewer tire tracks. Human constructs to control the shape of the beach were present at Ocean City in the form of a jetty adjacent to OC 1, as well as a boardwalk (Figure 4). At Ocean City there were numerous footprints throughout the beach, while at Assateague there were not as many. A parking lot was located directly past the berm at Ocean City, as well as multiple buildings connected to the parking lot. At Assateague Island, there were large dune areas past the berm before reaching the parking lot at both data collection locations. The only buildings near the study area in Assateague were two small shower rooms between the berm and the parking lot at AS 1. Both AS 1 and AS 2 were next to large parking lots that had flat boardwalks leading to the area of the berm where the transect was started.

RCP Analysis

When comparing each RCP analysis between Ocean City, Maryland and Assateague Island, Ocean City experienced a higher percent of flooding (Table 2). Even though Ocean City might experience a higher percent of flooded land, the total amount of flooded land will be lower than that of Assateague Island (Table 2). In both Assateague Island and Ocean City, Maryland, the rates of flooding appear to be worse on the backshores compared to the ocean facing shores (Figures 5 and 6). It is easier to see that the parking structures and roads were flooded at Ocean City by the fact that they appear outlined by flood water, but in both Ocean City and Assateague, all roads and parking lots will be flooded, which accounts for most of the inland flooding (Figures 5 and 6).

Discussion

Based on our results, our hypothesis that the sea levels at Assateague and Ocean City will have different beach profiles and will show different levels of flooding through the RCP simulations was supported. Our results show that, Ocean City will become 37% flooded and Assateague will become 32% flooded if climate change follows the IPCC trends for RCP 2.6 (Table 2). This flooding will cause a large portion of the islands to be confronted with the issue of whether or not they can adapt to the changes and damage from sea level rise. Many studies reveal that the stability of the environment will surpass the RCP 2.6 projection, as global temperature change is very likely to exceed 3.6° Fahrenheit (Wuebbles et al., 2017). As increased storm intensity occurs due to climate change and sea level rise, barrier islands are beginning to migrate inland as a response to sand being deposited at a greater rate (Deros et al., 2017). In a previous study performed by Deros et al. (2017) over a 32 year period, the beach area of Assateague Island decreased by 0.64% and the water area increased by 2.47% when studying the impacts of future sea level rise on different National Parks . This shows that water is overpowering the available land on the island, and it is decreasing the size of the beach, affecting the beach profile.

In addition, Assateague Island is moving west in response to sea-level rise and island rollover (NPS, 2015). During extreme weather events, such as hurricanes or nor'easters, sand becomes eroded and carried across the island by flood waters and is being deposited on the Western shore, which in return is narrowing the bay which separates the mainland and island (NPS, 2015). Additionally, the extreme whether events can break dunes, which spills sand into fanlike deposits or caving inlets, and longshore currents overtime will erode shoreline sediments unless Assateague Island is maintained with jetties or dredging (NPS, 2015). When combining the westward movement of the island with erosion from sea level rise, the island could diminish at a fast rate, having cultural, ecological, and economic consequences. Beach profiles at Ocean City also have lower reliefs and shows generally flatter beach profiles than at Assateague Island. (Figure 3; Table 1). This means that low relief, flat beaches will be increasingly susceptible to inundation from sea level rise and will flood more easily (Figure 5). This combined with erosion will drastically impact shorelines and beach profiles.

Over half of Assateague Island is composed of nearshore and estuarine waters, and the water at this location in relationship with this barrier island impacts a majority of life in this coastal environment (NPS, 2017). Backbarrier or backshore environments are the areas of barrier islands that face the mainland, sometimes referred to as the bayside of barrier islands, and usually includes salt marshes and other wetlands, as well as a bay or inlet (Deaton et al., 2017). Because Ocean City and Assateague Island contain large areas of wetlands, flooding severely impacts the wetland ecosystems under any of the three RCP simulations. An increase in frequency of storm surge and intensity of storm surge is a pressing issue for barrier islands due to their shape and size and the fact that they are often the first land masses to experience flooding and storm surges (Houser et al., 2018). Barrier islands are important ecologically because they act as protectants for storm surges and wave actions for the mainland, as well as their ability to help control erosion, purify water, act as a carbon sink, and create areas for fisheries (Epanchin-Niell et al., 2017). As barrier islands are put at risk from sea level rise, their ability to do these ecosystem services becomes diminished (Epanchin-Niell et al., 2017). As storm intensity increases as a result of climate change, beaches along barrier islands will erode at an increasing rate, which will further aggravate the damage that sea level will have for barrier islands (Houser et al., 2018). Inundation in this region will also result in an increase the salinity content in rivers, bays, and aquifers (Scavia et al., 2002). The change in salinity of the water will have impacts on the dynamic of aquatic ecosystems and will force those species to adapt, migrate, or become extinct (Scavia et al., 2002). The salinity changes could also attract new species to this area, which can alter prey-predator interactions and competition of available resources among species (Scavia et al., 2002). This could further cause species to become endangered or extinct (Scavia et al., 2002).

A multitude of species inhibit Assateague Island including a variety of rodents, mammals, reptiles, amphibians, and birds, many of which are endemic or specialist species that are unable to live in other locations (NPS, 2019). Assateague Island is seasonally home to many bird species, many of which rely on the island's protected shores, which contain foraging, rest areas, and nesting sites during migration (NPS, 2019). Through climate change and sea level rise, both terrestrial and marine species have begun, and are further going to be impacted through the loss of habitat and habitat fragmentation (Kumar and Tehrany, 2017). This has already been seen at both Assateague and Ocean City, but is going to become exponentially worse (Kumar and Tehrany, 2017). As sea levels increase terrestrial landforms, like sand dunes, are at risk from constant flooding which could cause the terrestrial plant species living on the sand dune to move further inland or die out (Martin et al., 2018). This can be problematic if the migrating plant species outcompete other plant species or if they disappear completely and they were important habitats for other terrestrial animal and insect species (Martin et al., 2018). Because many of the species present at Assateague are endemic, the effect that sea level rise will have on habitats and species composition, many species will become endangered or extinct (Kumar and Tehrany, 2017; Martin et al., 2018; NPS, 2019). A change in habitat structure due to sea level rise leads to different prey and predator dynamics as species become less abundant or go extinct (Scavia et al., 2002). This change causes ongoing problems with species becoming endangered or extinct in a positive feedback loop (Scavia et al., 2002).

The land on Assateague Island has traditionally been used for grazing horses and livestock, as a location for fishing villages, aquaculture industry, and industrial sites (NPS, 2017). As sea level rise becomes a threat to these coastal regions, this local ecosystem will experience a variety of changes, impacting the livelihoods of many people who rely on this land for jobs within the industries mentioned (Houston, 2008). Specifically in the fishing industry, fishermen will have to go further and work longer hours to increase their yields, or risk having lower yields, affecting their overall income (Houston, 2008). This will impact economies in Assateague and in the local communities.

Unlike Assateague Island which is a National Park and has little in the way of infrastructure, Ocean City will face the consequences of sea level rise through the inundation of high-rises and other permanent structures (Letherman, 1987). A study by Letherman (1987) found that the shores of Ocean City had retreated about 75 meters between 1850 and 1980, and with our RCP projections of sea level rise and flooding, the shores of Ocean City will continue to retreat at an alarming rate. This is going to cause increased problems with high-rise flooding and damage to unstable infrastructure (Letherman, 1987). Unfortunately, predictions of storm and flood damage of these beachfront communities is expected to outweigh the extent that the United States government's budget can allocate towards reconstruction of affected areas, applying to both Ocean City and Assateague (Dinan, 2017). In locations such as Ocean City, the local economy relies on the beachfront properties they boast as well as the tourism industry (Dinan, 2017). In the event of severe storms or a scenario as drastic as the RCP 8.5 model, flood damage has the potential to ruin the worth of this beach town as a whole as the coastline gradually inches closer inland (Dinan, 2017). A decline in tourism in this area would seriously hurt small businesses such as restaurants, attractions, shopping centers, recreational sites, and hotels, worsening a large extent of this local economy.

A study performed by Deros et al. (2017) found that Assateague Island National Seashore could experience damages totaling up to $141,894,898 due to loss of infrastructure and cultural assets in response to future sea level rise. The loss of this island would take away from the inherent value of this estuarine ecosystem, both ecologically and economically (Deros et al., 2017). Epanchin-Niell et al. (2017) discuss the monetary value of losses in inundated wetland areas due to seal level rise, approximating that the average annual storm protection value of coastal wetlands along the east coast is $8,235 per hectare . If a monetary value is placed on the losses that beaches and coastal communities face through sea level rise, it becomes evident that governments will not be able to afford reconstruction costs. However, it should still be emphasized that this land is extremely valuable and its loss due to sea level rise would have major consequences for the environment as well as the economy. Sea level rise impacts infrastructure in terms of damage to buildings and roads, as well as damage to local jobs through the damage of buildings, a reduced fishing industry, and a reduction in tourism, affecting the local economy, and the amount of money that can go towards local conservation efforts, both at Ocean City and Assateague (Deros et al. 2017; Houston, 2008). Houston (2008) discovered that about one in nine people are employed through the travel or tourism industries in the US, so many people's livelihoods would suffer as a result of land loss on these barrier islands. Tourism is an irreplaceable commodity because people travel to specific geographical locations for their uniqueness, and the experience cannot exist without the actual place. Houston emphasizes the benefits of beach nourishment through the example of Miami Beach, almost completely gone in the 1970's, but was able to regenerate (2008). Now Miami has more than doubled its annual visitors than it did initially, and this could serve as a model for both Assateague Island and Ocean City because the local economy in Florida thrives from the appeal that Miami has to tourists, only of course if Maryland's budget has the flexibility (Houston, 2008). This would be a struggle for Assateague and Ocean City to afford because of the size difference, but it could be a start at looking at ways to increase funds for beach nourishment.

We found that there was a difference in the amounts of flooding that happened at Ocean City and at Assateague. We looked at Ocean City as a developed shoreline and Assateague as an undeveloped shoreline to see if there would be a difference in severity of potential flooding. We found that Ocean City had higher percentages of flooding under all RCP simulations compared to Assateague, but that the amount of land that was flooded was smaller (Table 2). This is due to the differences in total land size that were used in this analysis, but also because of the differences in elevation at developed versus undeveloped beaches and barrier islands. Developed barrier islands and beaches tend to have lower relief to accommodate the intense infrastructure that goes with coastal towns and cities (Dinan, 2017). Undeveloped beaches and barrier islands, such as Assateague, have larger reliefs because they do not have to cater the land to accommodate as many buildings and roads (Dinan, 2017). This means that developed shores will experience more severe flooding as sea level rises compared to undeveloped shores and barrier islands.

Some limitations to our research include disturbance at both beaches, potentially affecting the elevations that were collected. Additionally, the poor weather conditions on the day of the data collection limited the sample size of locations. More data collection locations at both beaches could have improved the accuracy and thoroughness of the profile data. We were limited by the cold and the rain in terms of how many beach profile transects we were able to collect. There was also a limitation to the scope of area we were able to analyze. Due to the large size of our LiDAR DEM set for both Assateague Island and Ocean City, we limited the area on which we performed the RCP simulations to the portion of Assateague Island that falls within Maryland's borders in Worcester County . Additionally, data indicating the type of land (developed or undeveloped) being affected by sea level rise would also be more helpful to compose a clear evaluation on the extent of damage to the vulnerable coastal location, but that was outside the scope of the data we collected.

Future research on this topic could collect more detailed beach profiles at more locations in both Assateague and Ocean City. Future studies could also look at how beach profiles would change depending on the season they were measured, to show how differences in seasonal weather and climate impacts beach profiles. In addition, it would be helpful to look at historic imagery or data of the beach profiles of Assateague and Ocean City, as well as historic records of sea level changes, to look at the trends of the past and how they compare to future projections of sea level. It would also be interesting to look at different beaches and barrier islands on the East coast to compare them to Ocean City and Assateague. Other locations could show similar patterns of sea level rise, but could also show differences depending on the beach profiles and elevation of different areas. It would be especially interesting to look at the different effects that sea level rise has on barrier islands versus mainland shores to see if there is a difference. Looking at barrier islands or shores at different latitudes could also be an interesting way to determine if climatic zones, from the tropics to the Arctic, would have an impact on beach morphology and sea level rise.

Conclusion

Based on our results, we support our hypothesis that Assateague Island and Ocean City will have different beach profiles as shown through the differences in average elevation change at Ocean City and Assateague. We also accepted our hypothesis that the percent of flooding would be different at each location for each RCP simulation. Looking into the future, the impacts of sea level rise due to climate change and anthropogenic activities should be actively communicated and made aware to the public for an understanding of the implications of such environmental changes. The results of our studies show that even with the lowest RCP scenario, land in Ocean City, MD and Assateague Island, MD will experience loss of land and changes in beach profile due to sea level rise. Sea level rise will have drastic implications, both for ecological and economic systems. Mitigation efforts must be implemented in these vulnerable areas in order to avoid the worst case scenario RCP projection.

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Tables and Figures

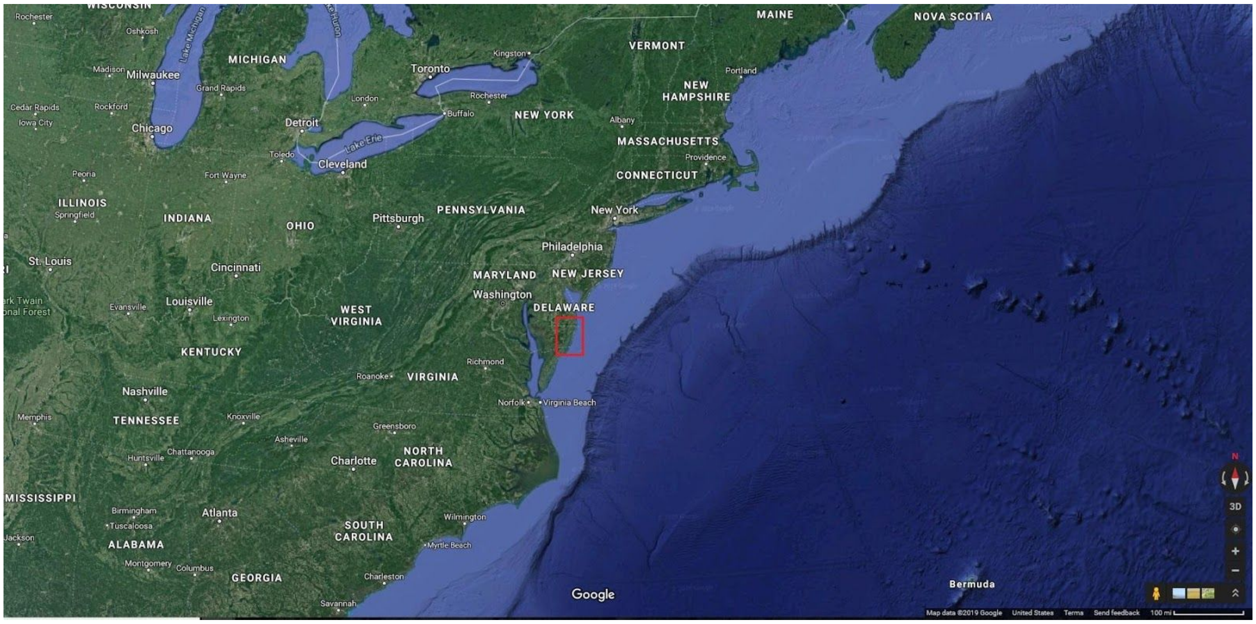

Figure 1a. The study areas of Ocean City, MD and Assateague, MD are highlighted in red to show their relation in regards to the surrounding area.

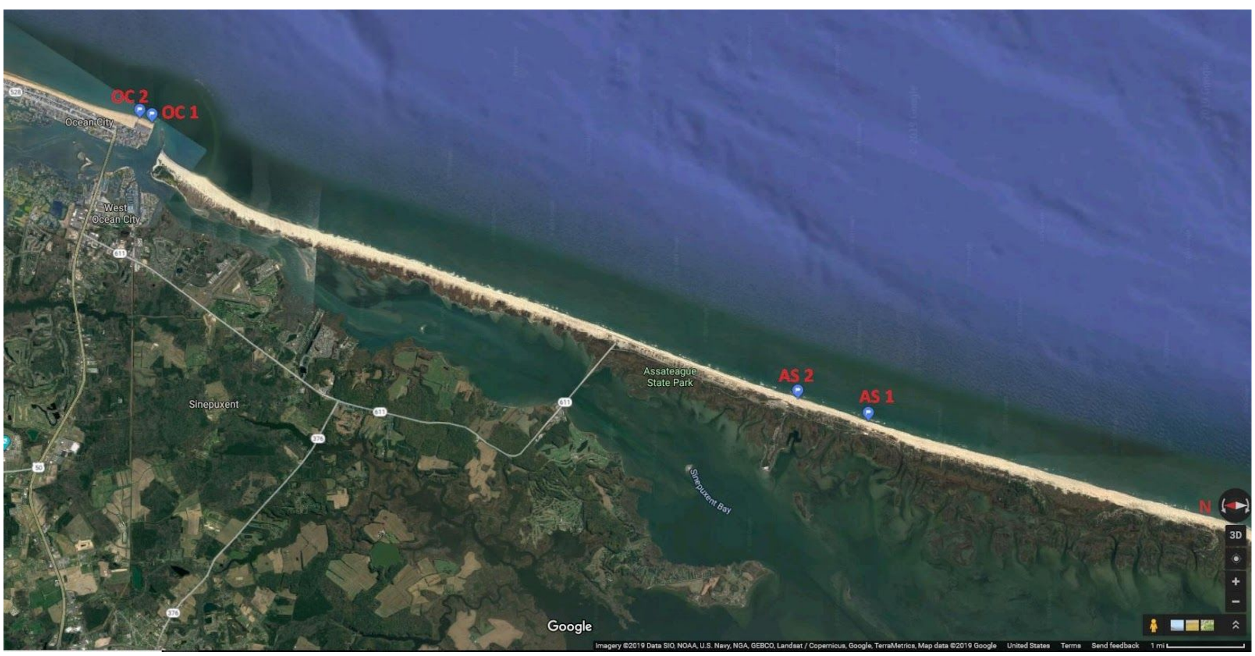

Figure 1b. The study sites showing the location of the four transects, with OC referring to the two at Ocean City, and AS referring to the two does at Assateague. (North is to the left in this image)

Figure 1c. The Ocean City, MD, study site, containing both OC 1 and OC 2.

Figure 1d. The Assateague, MD, study site, containing both AS 1.

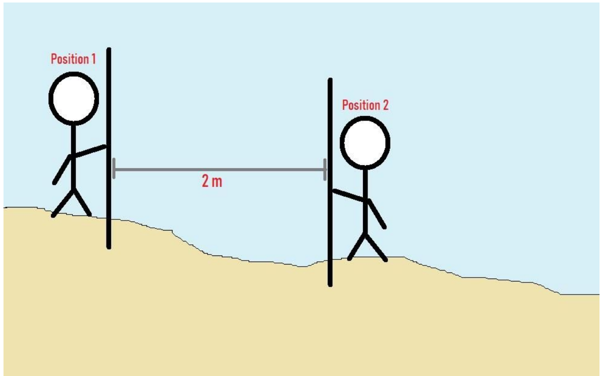

Figure 2a. An artistic representation of how the beach profiles were measured.

Figure 2b. Group members Gabby and Cara measuring the beach profile at OC 2.

Figure 2c. An example of the meter stick/ pole that was used to conduct the beach profiles.

Figure 2d. An example of the transect line that was used to conduct the beach profiles.

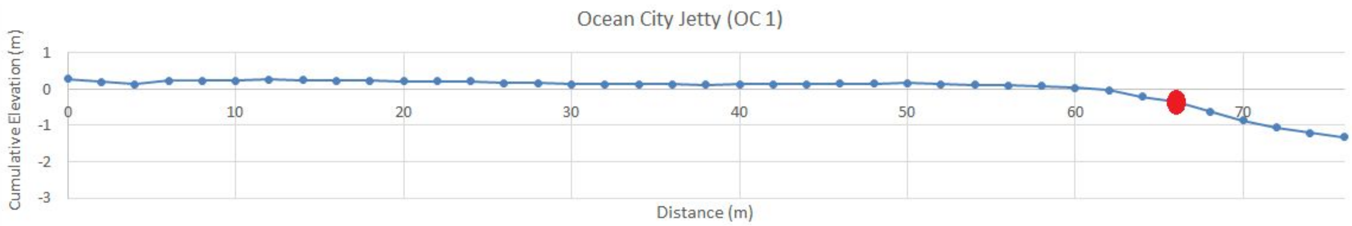

Figure 3a. The cumulative elevation beach profile of the first location at Ocean City, MD, which was located adjacent to a man-made jetty. The red dot refers to the high water mark.

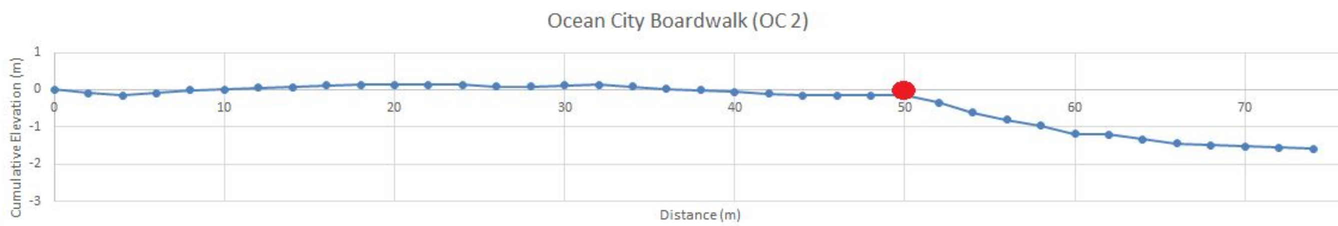

Figure 3b. The cumulative elevation beach profile of the second location at Ocean City, MD, which was located adjacent to a raised platform boardwalk. The red dot refers to the high water mark.

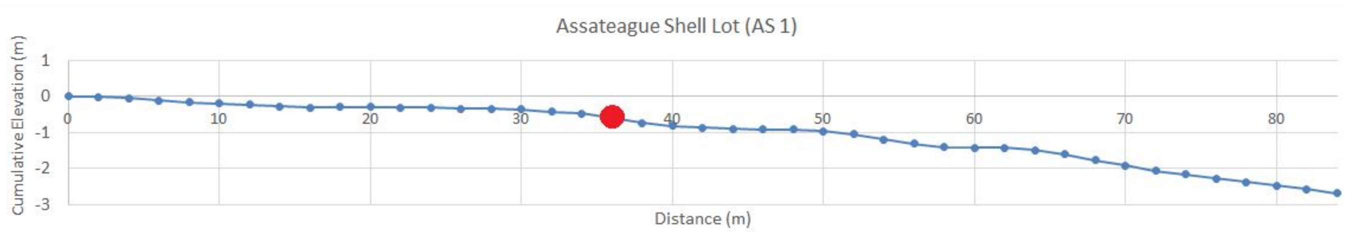

Figure 3c. The cumulative elevation beach profile of the first location at Assateague, MD, which was located across from the shell parking lot at South Beach. The red dot refers to the high water mark.

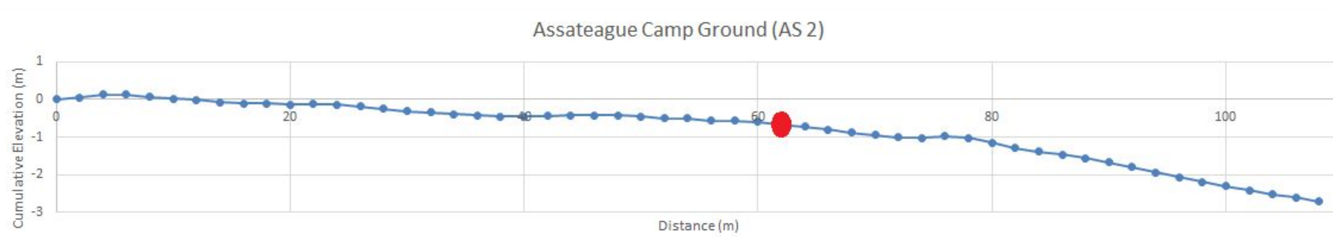

Figure 3d. The cumulative elevation beach profile of the second location at Assateague, MD, which was located at the group camp site. The red dot refers to the high water mark.

Figure 4a. The jetty at Ocean City, adjacent to OC 1.

Figure 4b. The boardwalk at Ocean City, MD, adjacent to OC 2.

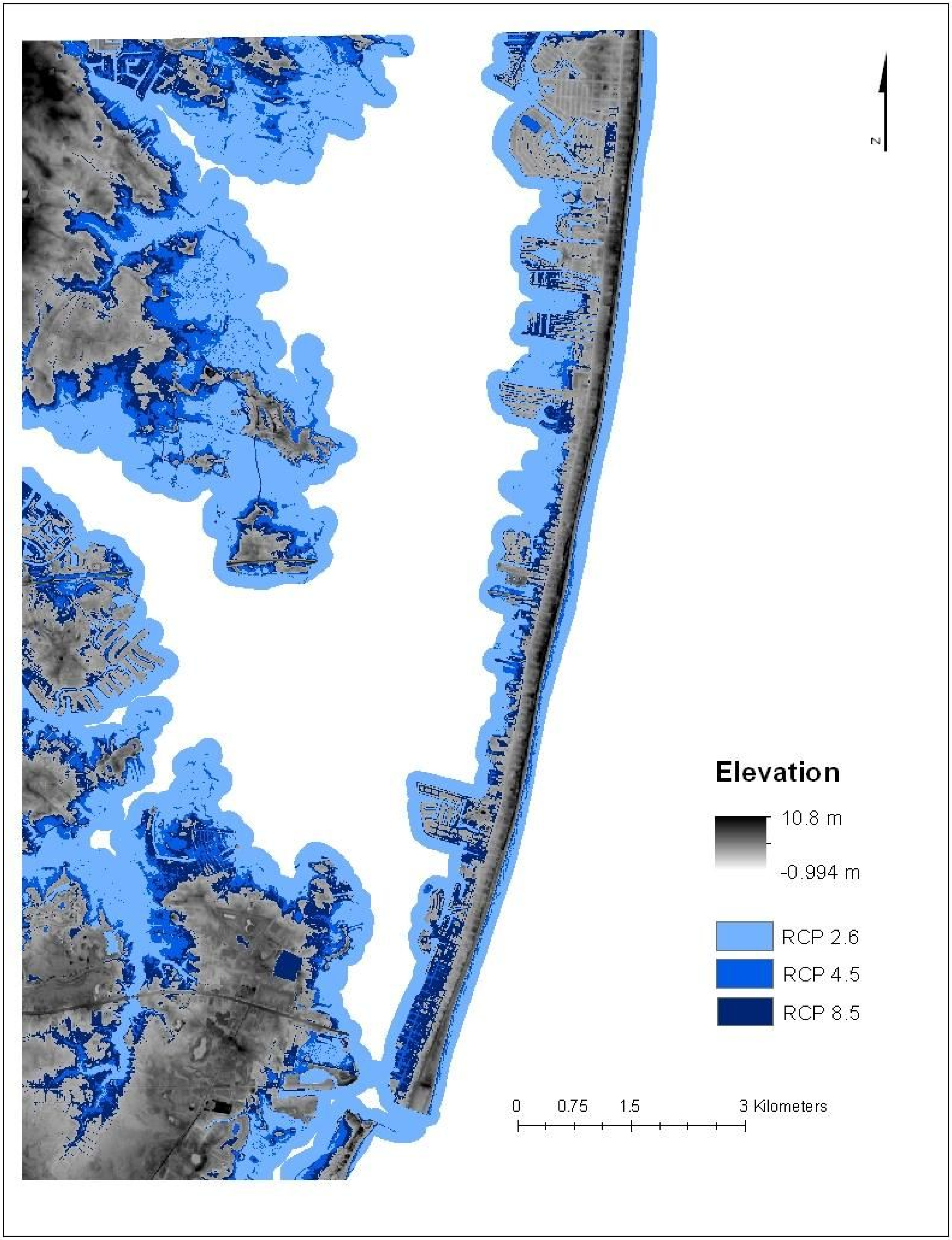

Figure 5. The area of Ocean City, MD, showing all RCP simulations for the year 2100, including the OC 1 and OC 2 transect areas.

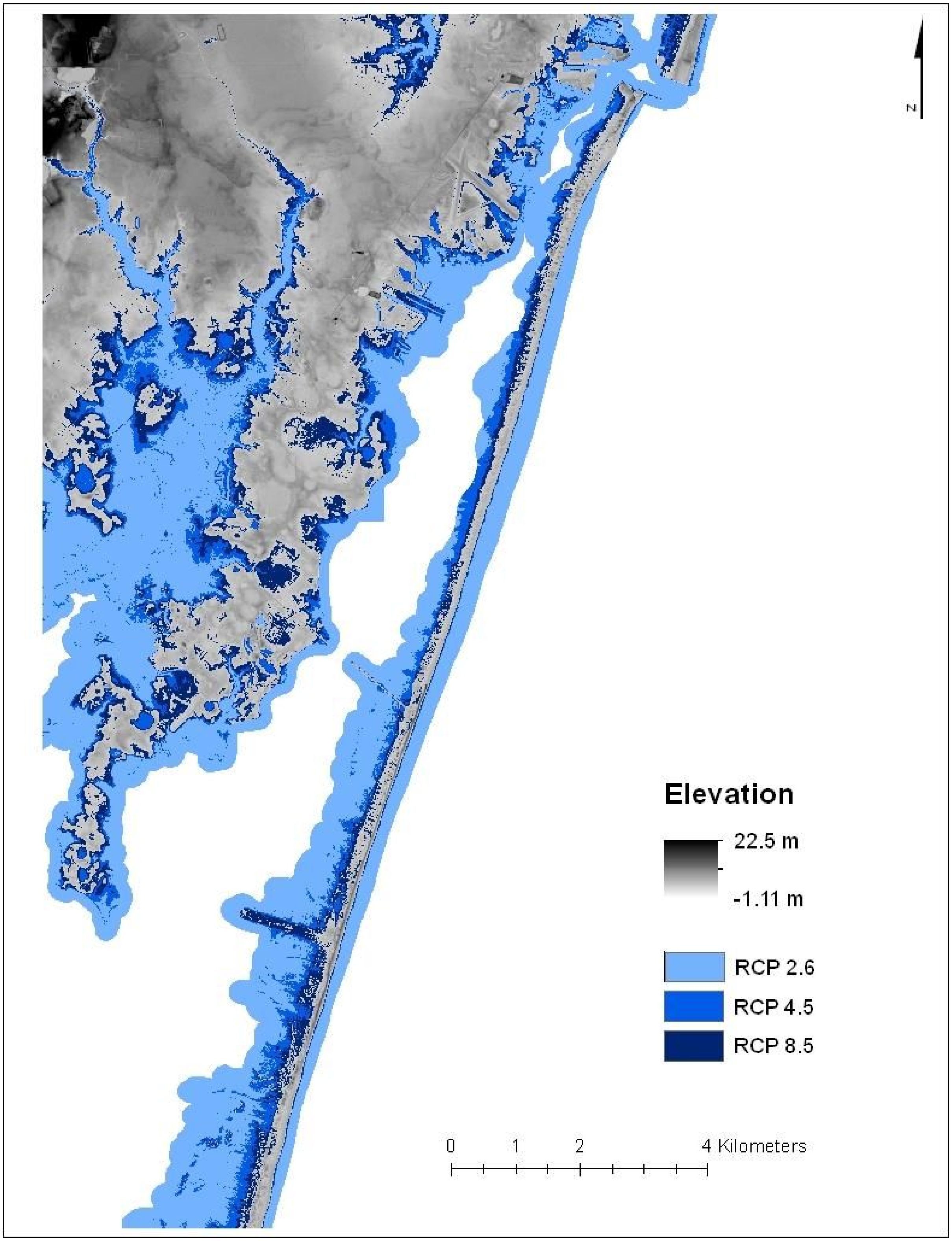

Figure 6. The area of Assateague, MD, showing all RCP simulations for the year 2100, including the AS 1 and AS 2 transect areas.

Table 1. The average change in elevation for each beach profile transect.

Transect Location	**Change in Elevation (cm)**
OC 1	-3.38
OC 2	-4.00
AS 1	-6.26
AS 2	-4.96

Table 2. The numerical calculations of the percent of flooded land after each RCP simulation for Ocean City and Assateague as well as total flooded land after each simulation based on IPCC predictions for the year 2100.

	Sea Level Increase (m)	**Percent of Flooded Land (%)**	**Area of Flooded Land (km^2)**
Ocean City RCP 2.6	0.5	37.02	26.58
Ocean City RCP 4.5	1.0	46.31	33.24
Ocean City RCP 8.5	1.5	57.83	41.52
Assateague RCP 2.6	0.5	32.79	31.83
Assateague RCP 4.5	1.0	40.72	39.53
Assateague RCP 8.5	1.5	49.76	48.30

Appendices

	Location 1: OC 1 (38°19'28.9632" N 75°5'3.3876 "W)	Location 2: OC2 (38°19'37.3296" N 75°05'5.5258"W)	Location 3: AS 1 (38°11'25.0044"N 75°9'26.2075 "W)	Location 4: AS 2 (38°12'12.726" N 75°9'6.9850" W)
0 m	28	0	0	0
2 m	-8	-9	-1	5
4 m	-7	-6	-4	8
6 m	10	6	-5	0
8 m	0	8	-6	-7
10 m	1	2	-3	-5
12 m	2	5	-4	-3
14 m	-1	1	-4	-5
16 m	-1	4	-3	-4
18 m	0	2	1	0
20 m	-2	0	0	-3
22 m	0	0	-1	2
24 m	-1	0	0	-2
26 m	-4	-4	-3	-5
28 m	0	0	-1	-6
30 m	-3	3	-2	-7
32 m	-1	1	-6	-3
34 m	1	-5	-5	-5
36 m	-1	-6	-13	-3
38 m	-1	-3	-13	-2
40 m	1	-5	-8	0
42 m	1	-4	-6	1
44 m	0	-6	-3	1
46 m	1	1	-2	0
48 m	1	-1	0	0
50 m	1	1	-4	-2
52 m	-3	-20	-9	-6
54 m	-2	-27	-14	0
56 m	-1	-18	-12	-5
58 m	-2	-17	-9	0
60 m	-6	-22	-2	-4
62 m	-7	-1	-1	-6
64 m	-17	-14	-6	-6
66 m	-16	-10	-11	-9
68 m	-26	-5	-16	-7
70 m	-25	-3	-16	-6
72 m	-19	-3	-14	-7
74 m	-14	-3	-11	-2
76 m	-12		-11	5
78 m			-10	-4
80 m			-10	-13
82 m			-10	-14
84 m			-11	-10
86 m				-8
88 m				-9
90 m				-11
92 m				-13
94 m				-14
96 m				-13
98 m				-13
100 m				-11
102 m				-10
104 m				-11
106 m				-9
108 m				-10

Appendix 1. The raw data of change in elevation for each beach profile with the HWM, high water mark, highlighted in yellow.