Research completed: May 2023

Published: May 2024

PLUM ISLAND: LOOKING AT A VULNERABLE LANDSCAPE

A study about the dangers of sea level rise and erosion

Rowan Collins
a_collins7@salemstate.edu
Faculty sponsor: Professor Lorri Krebs

Table of Contents

1. Introduction 2
2. Methodology 2
3. Literature Review 3
   3.1 Sea Level Rise and Flooding 3
   3.2 Erosion 4
   3.3 Housing Loss 4
4. Content Analysis 5
   4.1 Sea Level Rise and Flooding 6
   4.2 Erosion 8
   4.3 Housing Loss 8
5. Discussion 10
6. Solutions 10
7. Conclusion 14
8. Bibliography 15

1. Introduction

Climate change is slowly becoming one of the most commonly discussed modern issues in the world. In a survey spanning 19 countries, the majority of people considered climate change to be a major threat to their country. In the UK, for example, 75% of people considered climate change to be a major threat in 2022, in comparison to 48% in 2013 (Fagan et al., 2022). Among the major threats associated with climate change, Sea level rise (SLR) is one of the most well-known and threatening, bringing with it erosion, flooding, and property damage or loss. Especially at risk are coastal communities such as Plum Island, Massachusetts, a small town in Newbury located on a barrier island. Barrier islands are a deposit of sand that forms parallel to the coast, named for their role in protecting coastal communities and ecosystems from extreme weather (NOAA, 2021). They are particularly vulnerable to erosion, especially when caused by human activity, so their conservation should be considered a priority in order to preserve the property located on them, as well as the ecosystems they foster.

This study uses Plum Island as its focus to explore the threat of sea level rise, erosion, and flooding, their impact on housing and property, and potential solutions. This study explores if Plum Island has seen an increase in flooding over the past 10 years, whether this has led to increased property damage and erosion, what solutions have been recommended or attempted, and how Plum Island's current situation compares to the rest of the world's experiences. This research report will provide valuable reference to those attempting to understand the potential consequences of climate change, the risks Plum Island faces, and potential courses of action that can be taken.

2. Methodology

This paper employs a content analysis of different literature regarding sea level rise and the current and predicted consequences that will be seen around the world, with a focus on Plum Island, Massachusetts. Another content analysis of a similar nature was

conducted with a focus on Japanese perspective, titled “Sea-level rise caused by climate change and its implications for society”, written by Nobuo Mimura (Mimura, 2013). This intent of this research is to explore other published studies to create a comprehensive look at Plum Island’s potential future, and courses of action that should be taken. Data was collected via the internet, mainly through peer-reviewed sources and studies, then analyzed through the lens of Plum Island’s current situation and needs in order to provide a comprehensive look at potential futures and solutions.

3. Literature Review

The impacts of climate change are found nearly everywhere, and thus appear in many reports and studies. Generally, the most vulnerable areas are located on the coast, near the water. Increased tropical storms, flooding, and sea level rise all threaten these places with large amounts of destruction and economic loss. In order to understand how a singular area may be affected, it is important to consider the impacts sea level rise has on multiple areas, and the effects that have been observed or predicted by others. This review of the related literature will examine three areas: (1) sea level rise and flooding, (2) erosion, and (3) housing loss.

3.1 Sea Level Rise and Flooding

The effects of sea level rise have been studied on many different occasions, and the impacts currently being seen do not bode well for the future. On the Senegalese coastline, the impacts of climate change were studied at two representative locations: the Cap Vert peninsula and the Saloum Estuary. With a 1-meter inundation level, an estimated 27% of the Saloum Estuary will be lost. With this same inundation level, between 1 and 12% of the population of the Cap Vert peninsula faces flooding (Niang et al., 2010). Sea level rise is not the only factor influencing flooding. Tropical storms, particularly hurricanes, are expected to increase worldwide in both intensity and frequency. This is particularly the case in the Northwest Pacific and western North Atlantic. Three cities highlighted in a study examining this were Wilmington (North Carolina), Charleston (South Carolina), and New Orleans (Louisiana). This study estimated that if the correlation between sea level rise and tropical cyclones were

ignored, “the average projected change to the historical 100 years storm tide event is under-estimated by 12%” (Lockwood et al., 2022).

3.2 Erosion

As a result of rising sea levels and increased storms, erosion is also expected to increase in intensity. According to a 2006 study on the effects erosion has on the tourism industry, “a 0.3m rise in sea level would cause an estimated 30m erosion” (Phillips and Jones, 2006). Cape Cod, Massachusetts is an example of a coastal community facing heavy risk from erosion. The area is expected to experience property loss, habitat loss, and infrastructure damage, and already, erosion has increased “from a 1.9 m over the last 2,000 years to .3 m in just one year” (Roberts et al., 2015). Additionally, drift-aligned deltas were examined on the South African coastline. These are deltas positioned in a way that waves break at an angle to the coast. Specifically, the Diep River near Cape Town and the Umgeni River at Durban were used as examples. In these cases, erosion wore down the rivers, making nearby developed areas more vulnerable to damage from flooding and waves (Hughes and Brundrit, 1995). Combating erosion is an expensive and labor intensive process. The Miami-Dade area of Florida is estimated to need roughly 20 million cubic yards of sand over the next 50 years in order to maintain its beaches (Anderson et al., 2016).

3.3 Housing Loss

Housing loss often occurs as a result of intense storms, flooding, and erosion, particularly near the shoreline. The majority of people live in coastal communities, giving much weight to the threat of coastal erosion and inundation. In the Miami-Dade region of Florida, there has been over $465 million lost in real estate market value between 2005 and 2016 (McAlpine & Porter, 2018). This trend is expected to occur in South Africa, where there is development along unstable coastlines, something that will likely lead to shoreline collapse and properties being lost (Hughes and Brundrit, 1995). A study was conducted to estimate how many properties will be lost to sea level rise in 15 major U.S. coastal cities, with the results being rather grim. It was estimated that between 2,000 and 28,000 properties will be inundated by 2100 under a relatively low greenhouse gas scenario, equating to between $0.1 to $1.8 billion in economic losses

(Rodziewicz et al., 2020). Chatham County, Georgia, is expected to lose approximately 6,100 homes, and $2.1 billion worth of property. Nearly $150 billion of property is threatened in the Charleston area of South Carolina, and $75 billion worth of property could be lost over the next 75 years in just four of North Carolina's counties. Similarly, a 3.3 foot sea level rise in Maine would inundate an estimated 20,000 acres of coastal real estate, destroying 53 miles of road and a potential $46.4 million to $111 million of real estate in Portland (Anderson et al., 2016). In order to combat the increased loss of property, many places have implemented building codes and policies to reduce damage. In the late 1980s, Helsinki, Finland, raised floor levels in an inner-city suburb to 3 meters above sea level. In 2011, Christchurch, New Zealand, created provisions to control development in areas vulnerable to flooding, which included raised floor levels and setbacks from waterways. Finally, "Vancouver, Canada, updated minimum flood construction levels to be a metre higher in 2014 to account for SLR projections up to 2100" (OECD, 2020).

The effects of climate change, particularly sea level rise, have been observed all over the globe. There are many facets of this issue to consider, such as the effects it may have on populations, shorelines, housing, and erosion, as well as many potential solutions to consider. Sandbagging, dredging, seawalls, and new building codes have all been considered and attempted in order to mitigate negative impacts. With current trends, many areas close to the shore, especially those with low elevation, stand to lose large amounts of land, property, and revenue. This is not only expensive, but also a threat to human health and safety, as many members of the population could end up without shelter or at risk as a result of flooding.

4. Content Analysis

As climate change worsens, and becomes more of a threat to property and human health, coastal communities arguably stand to lose the most. This is particularly the case as sea levels rise, and floods become more destructive, as well as more frequent. Plum Island is a small island off the coast of Massachusetts, a part of the town of Newburyport, and it is currently seeing the dangerous impacts climate change can have. This fact makes it a prime location to be studied in order to better understand the

effects of sea level rise (SLR), and strategies that can mitigate it. As such, there is much literature related to the negative effects of sea level rise, and adaptation and mitigation strategies. This content analysis will include three areas: (a) data regarding sea level rise and shoreline changes, (b) potential impacts and consequences this will have, particularly on housing, and (c) potential solutions to this issue.

4.1 Sea Level Rise and Flooding

Sea level rise is a dangerous environmental change that affects many places and aspects of human life, particularly on the coast. As of now, "The present population at risk (*i.e.*, people living in areas inundated by a 1/100 year storm surge) is estimated to be 270 million people worldwide" (Mimura, 2013). In a study conducted on the Cap Vert peninsula in Senegal, it was found that between 1 and 12% of the total population faces inundation risk with a 1 meter increase in sea level. In low-lying areas such as the Saloum estuary, this increase could result in 27% of the total area lost (Niang et al., 2010). Dakar, Senegal, near where both these areas are located, does not exceed 104 meters (~341 feet) in elevation ("RedGems", n.d.). Plum Island has an elevation of about 10 feet (~3 meters), putting it at a higher risk of inundation as sea levels rise.

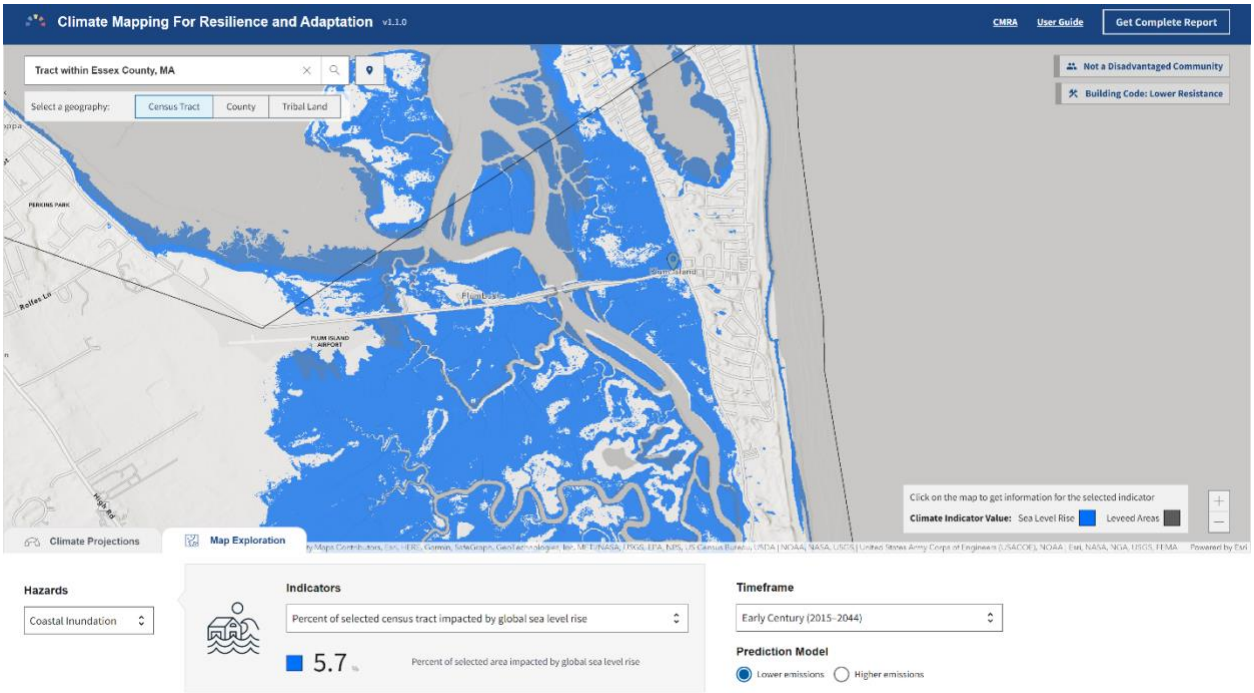

Fig. 1 Source: Climate Mapping For Resilience and Adaptation

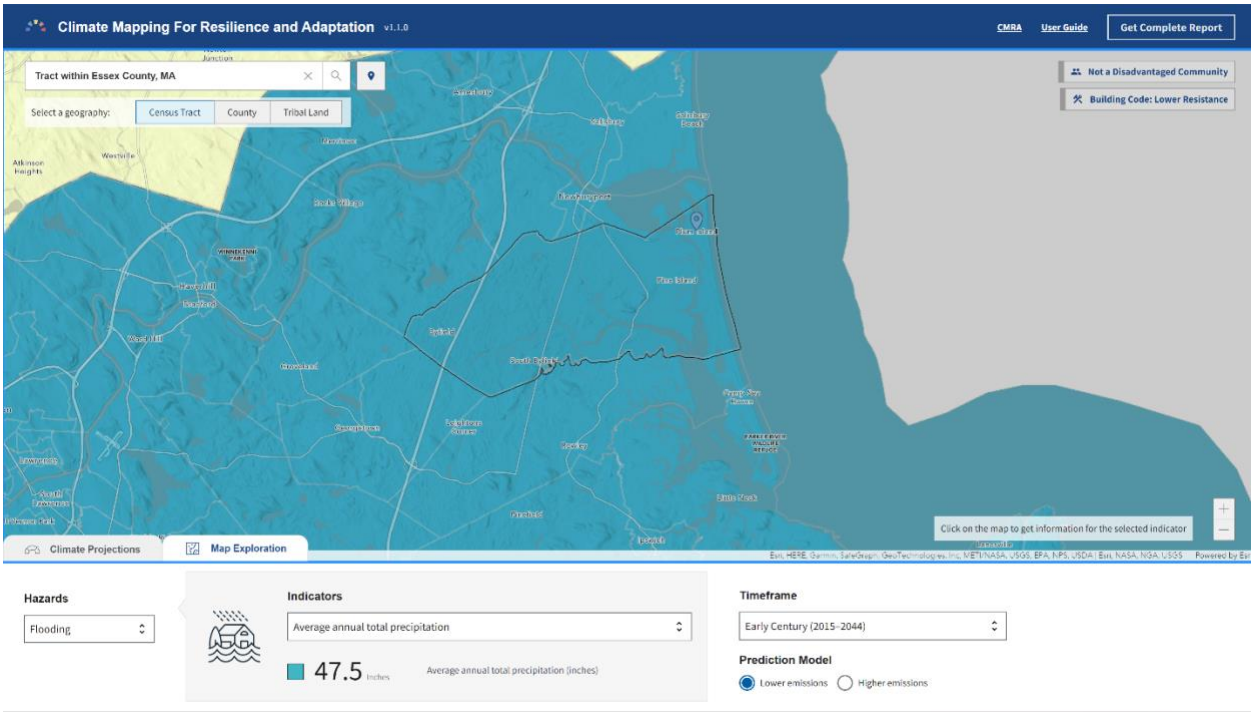

Fig. 2 Source: Climate Mapping For Resilience and Adaptation

As shown by Fig. 1 and Fig. 2, data provided by Climate Mapping for Resilience and Adaptation shows the risk of flooding and sea level rise inundation that Plum Island faces. Even in a lower emissions prediction model, meaning a future scenario where humans drastically reduce their use of fossil fuels, Plum Island is shown to be at a high risk of flooding due to increased annual precipitation, combined with fewer “wet days” (days with precipitation). These factors in combination lead to heavier rainfall at one time, causing flooding. This is the same case with coastal inundation, as the map shows in Fig. 1 (ArcGIS, n.d.).

The Great Marsh is a massive salt marsh spanning over 20,000 acres, the largest in New England. Not only is it a vital habitat for many different species, it also acts as “nature’s flood insurance”. The expanse of the Great Marsh dissipates waves before they reach inland, providing a barrier from storm surges. According to the National Wildlife Federation, “a single acre of healthy Atlantic coastal wetlands reduces property damage from hurricanes by an average of $3,300 a year” (Stewart, 2015). This marsh is, in large part, protected by barrier islands such as Plum Island. As sand dunes collapse and the island faces degradation, this puts the marsh in danger, and, by

extension, inland towns such as Essex, Salisbury, Rowley, Newbury, Newburyport, and Ipswich.

4.2 Erosion

On the South African coastline, SLR is contributing to coastal erosion that threatens housing located on deltas, something that is expected to occur on an international level (Hughes & Brundrit, 1995). This erosion has also been observed in Plum Island, on the marshes and shoreline. As far back as 1942, the changes of Plum Island's shoreline was observed in comparison to documents from 1827. At that time, Plum Island's northern end was not forked, however, in 1942 there were two prominent prongs forming a basin. This report posits that Plum Island may eventually retrograde southward, and the current basin will be destroyed (Nichols, 1942). Such changes have undoubtedly been exacerbated by increased sea levels and erosion, and whether or not a new basin will be formed could be affected by this as well. In addition to the shoreline, the marshes of Plum Island, which are incredibly important ecosystems, are also suffering from erosion and flooding. In a 2018 study, it was observed that tidal marshes have been gaining elevation at around the same rate as SLR. However, there is concern that this elevation gain will not be able to keep up if sea levels rise at an increased rate. Whether this will be the case is dependent on the sediment source. Since the primary source is from the erosion of creek banks and marsh peat, there is a heavy risk of marshes eroding too fast as sea levels rise, and eventually being inundated (Hopkinson et al., 2018). A similar conclusion was reached in a 2010 study, where it was determined that marshes with low amounts of suspended sediment would be inundated under more rapid projections of Sea Level Rise (Kirwan et al., 2010). The risk that marshes face most likely represents the dangers the rest of the island may encounter.

4.3 Housing Loss

There are many potential consequences of sea level rise, including loss of properties and revenue, and increased erosion. It has been suggested by studies that tropical cyclones and sea level rise have a joint influence, and may increase flood hazards

(Lockwood et al., 2022). Powerful storms destroying property on Plum Island have been noted as early as 1969, and possibly even earlier (Jones & Cameron, 1976). These hazards pose risk to housing, particularly in Massachusetts, New York, and New Jersey (Buchanan et al., 2010). Particularly at risk are affordable housing units, the number of which exposed to extreme water levels is expected to more than triple by 2050 (McAlpine & Porter, 2018). In the Miami-Dade area of Florida, another coastal community, it was estimated that flooding has resulted in over $465 million in lost real estate market value between 2005 and 2016 (McAlpine & Porter, 2018). This estimate provides a valuable look at what Plum Island's future could hold, given its similar proximity to the coast. Another perspective on this issue comes from a 2020 article that attempted to estimate potential housing loss in 15 major U.S. coastal cities. It was estimated that between 2,000 and 28,000 properties will be inundated in a relatively low-level greenhouse gas concentration scenario, resulting in between $0.1 billion and $1.8 billion in direct economic losses. In a higher level greenhouse gas concentration scenario, this number rises to between 7,000 and 77,000 properties, resulting in between $3.8 billion and $50.6 billion in losses (Rodziewicz et al., 2020). On Plum Island specifically, "property taxes on the island generate $7 million annually in revenue for the towns of Newbury and Newburyport. As houses and property are impacted by ever increasing storms, the economies of these island communities will be strained" (Anderson et al., 2016). In addition to storms, erosion from wave activity and other sources poses a risk to housing. This erosion is occurring at the "statistically insignificant rate of only 0.09 ± 0.6 m/y", however, this has still resulted in the loss of over a dozen houses in the past several years (Fallon et al., n.d.).

Concerns surrounding the degradation of Plum Island are not only present, but prevalent amongst residents. In a letter to the mayor, a resident stated "It is very alarming to witness on my beach walks the disappearance of the shore line and the large blocks of concrete, etc showing on the thinning strip of beach" (Abbott, 2021). The resident then urges the mayor to seek the help of an organization called Ecoplage in order to create lasting solutions to beach erosion.

5. Discussion

Climate change is a worldwide phenomenon, and the effects Plum Island is seeing are reflected in many other places. Beach erosion is a major concern in locations such as Florida and Cape Cod, also located in Massachusetts (Anderson et al., 2016; Roberts et al., 2015). On Cape Cod, the rate of shoreline change and erosion has increased from 1.9 meters over the past 2,000 years to 0.3 meters in one year (Roberts et al., 2015). Sapelo Island is a barrier island south of Savannah, Georgia. This island is a critical storm buffer for the mainland, and is home to the Blackbeard National Wildlife Refuge, which provides important habitats and sea turtle nesting grounds. If current sea level rise projections continue, the island will be completely inundated by the end of the century (Anderson et al., 2016). This is a situation that reflects Plum Island's predicament, as they are both important barrier islands being threatened by rising sea levels. While Plum Island is not likely to be completely destroyed, there will be damages to the shoreline and marshes that negatively impact the humans and wildlife inhabiting it.

Part of the dangers erosion presents is the loss of property and housing. Plum Island generates a total annual output of $8.7 billion from its tourism and recreational economy, and property taxes generate $7 million annually in revenue for Newbury and Newburyport (Roberts et al., 2015). The loss of properties will strain the local economy, something that is being observed worldwide. The Cap Vert peninsula in Senegal stands to lose 7.5% of its gross domestic product (GDP), of which more than 90% is housing (Niang et al., 2010). As previously mentioned, Plum Island is at a lower elevation than this area, meaning that if sea levels rise at the same rate, the island will lose even more land. For Cap Vert, 2 meters of inundation results in roughly 25% of the total land lost, and given the difference in elevation, it is not unlikely that this sea level change would be even more disastrous for Plum Island.

6. Solutions

Plum Island is seeing many solutions to attempt to combat its many pressing issues. According to "Changing Tides", "there are cost-effective natural solutions, such as planting dune vegetation, restoring salt marsh, and amending zoning regulations that

may ultimately provide the best chance at reducing the vulnerability of this barrier island" (Anderson et al., 2016). One of the biggest projects aimed at protecting Plum Island is a dredging project, meant to remove sediment from the Merrimack River and use it to expand Plum Island's beach. The amount of sediment was approved to be about 220,000 cubic yards, covering more than 9 acres of land (Massachusetts Energy and Environment Public Information, 2023; US Army Corps of Engineers, n.d.; City of Newburyport, n.d.). Studies have also suggested that mining areas near at-risk areas can reduce erosion by trapping sand and sediment, and building detached breakwaters can help protect Plum Island from wave impact, thereby also reducing erosion (Li, et al., 2018). Other solutions include avoiding construction in dangerous areas and using sandbags to minimize wave damage. Interestingly, the document that suggests these strategies also recommends avoiding using breakwaters, although it does not expound upon why (Walsh, et al., n.d.). An article on the Great Marsh suggests ceasing all building on barrier islands, in order to reduce as much erosion as possible (Stewart, 2015). This is a sentiment shared by many, as barrier islands are vital protections to many ecosystems and inland towns, and their development only serves to break them down faster, especially as climate change progresses (Zielinski, 2011). However, it is not feasible to remove all development, therefore, a better solution is to stop any further development that may negatively impact the area.

Whether engineered structures such as sea walls help to protect the beaches was investigated by the Environmental Technology students at Essex Technical and Agricultural High School. In addition to mitigation and adaptation projects, there are building laws and ordinances aimed at protecting structures. Currently, the city of Newburyport requires that all new construction on Plum Island be placed on pilings or piers, or "elevated at least two feet above the ground surface or FEMA base flood elevation" ("Plum Island Homeowners Guide", n.d.). Additionally, If work is being done on an existing home with a solid foundation in a flood zone, and the cost of that work is equal to or exceeds 50% of the value of the structure, then the whole structure must go up on pilings" ("Plum Island Guidelines", n.d.). The below photos were taken on Plum Island, and demonstrate the effectiveness of pilings in the event of flooding or inundation.

Fig. 3 Photography taken by Luke Shipman on Plum Island, MA

Fig. 4 Photography taken by Luke Shipman on Plum Island, MA

While there are many potential solutions to SLR and its effects on housing and property, there is the potential of laws and policies having the opposite of the desired effect. Coastal North Carolina counties experienced this, and Plum Island could potentially see this effect as well. In North Carolina, a scientific report mandating that SLR be considered when developing new policies resulted in an increase of building permits that negatively impacted the environment (Parton & Dundas, 2020). This potential downside should be considered when new laws or mandates are developed.

Additionally, a study done by the Environmental Technology Senior class of Essex Technical High school determined that structures meant to prevent erosion and wave damage were not effective in doing so. In this study, the class took measurements of beach width and height at different areas along plum island to determine whether strategies such as seawall construction, grass stabilization, and sand addition were able to prevent erosion. It was determined that the beach width was at its maximum on

undeveloped stretches, leading to the conclusion that beach loss was continuing even with mitigation strategies (Environmental Technology Seniors, 2015). This conclusion was reflected in a study on erosion and tourism, which found that seawalls and other hard engineering structures often promoted erosion, citing a case in Porthcawl, South Wales (Phillips and Jones, 2006).

7. Conclusion

Rising sea levels are leading to worldwide consequences that are becoming unavoidable. The most vulnerable areas to these effects are communities located on the coast, in close proximity with the ocean. As an inhabited barrier beach, Plum Island stands to lose much as a result of climate change. As such, it is of the utmost importance that the effects of sea level rise are taken seriously, and lawmakers take action to prevent as much damage as possible.

As the situation currently stands, the effectiveness of many mitigation tactics is up for debate. It has generally been found that seawalls and other hard engineering structures promote erosion and are not effective long-term solutions (Phillips and Jones, 2006; Environmental Technology Seniors, 2015). The strategy of dredging, which Plum Island is currently employing, has potential to be very effective, however, the type of sand being used must be carefully observed. At Marina Di Massa, a similar process was attempted, however, “The mean grain size of the borrow material was finer than the native beach sediment which resulted in approximately 66% of borrow material disappearing within one year” (Phillips and Jones, 2006). Overall, the most effective long-term solutions are to cease any more construction on the island, and to retreat. Retreating is the process by which homes and other structures are moved away from the shore. It is a complicated, timely process but ultimately more sustainable, and cheaper than rebuilding (Peabody, 2015; Moore, 2022). This should be used in combination with reinforcing the land using natural vegetation, in order to replenish areas where vegetation has been lost or overtaken by invasive species (Peabody, 2015).

Future research should attempt to estimate the economic losses Plum Island faces if sea level rise and erosion continue to get worse. This information is currently

only predicted based on current revenue and the losses of other areas. It is also worth further investigating the long-term effectiveness of certain suggested solutions such as grass stabilization, dredging, and building breakwaters. Lastly, it would be valuable for future research to measure and obtain tidal data on Plum Island, in order to have raw data regarding rising sea levels in this vulnerable area.

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