Coastal Erosion Mitigation on Nantucket

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Abstract

The goal of this project was to evaluate the use of various photo capturing technologies to document coastal land, analyze coastal erosion, and develop erosion mitigation proposals for selected public locations to add to Nantucket's Coastal Resilience Plan. To accomplish this, we utilized handheld photography, drone photography, and photogrammetry to document several public locations on Nantucket with high erosion rates. We used this information to qualitatively identify changes in the degree of erosion evident, compare the use of the different photo capturing technologies, and create plans for erosion mitigation at each site, including vegetation, sand fencing, and managed retreat.

Executive Summary

Introduction

The island of Nantucket is a result of a glacial moraine, a collection of sediment left behind as a result of glacial movements, that was built upon by tidal action (Hoff, 2021). This geological makeup creates an environment that is much more susceptible to erosion than landmasses with a base of bedrock. With the threat of losing land, houses, business, and government buildings, mitigating coastal erosion is an important issue for the island community.

Background

Erosion Control Methods on Nantucket

Several erosion control methods are currently being used on Nantucket, including sand fencing, beach nourishment, vegetation, and retreating. Sand fencing, wooden fence posts connected by wire, can be installed on a beach to capture windblown sand and build dunes. Beach nourishment is the process of importing sand to be deposited on a beach. Vegetation, such as the American Beachgrass native to Massachusetts, can be planted on beaches to stabilize dunes through their roots and catch windblown sand. Finally, retreating is the process of buildings being relocated to areas further away from coastlines to preserve both the structure and shoreline.

Technologies Used to Document Erosion

The most common and favorable way to document erosion is through forms of photography, including handheld photography, drone photography, and photogrammetry. Handheld photography provides a close-up view of the photos subject and is usually the highest quality image one can capture. Drone photography is utilized to take aerial photos of subjects from a distance, providing a view that is farther and higher than handheld photography can capture. Photogrammetry is the process of using specialized software to analyze a set of successive photographs taken from a single camera to recreate a 3D representation of the photos' subject. The representation, called a point cloud, is made up of discrete colored squares or circles to give the illusion of a 3D object. Figure 1 (following page) showcases how when zoomed out a point cloud appears like a 3D object, but zoomed in reveals the individual element.

Figure 1. Point cloud of Sconset Bluff in Potree
L: Sconset Bluff point cloud zoomed out
R: Sconset Bluff point cloud zoomed in (visible square points)
https://drone.farfetchednantucket.com/examples/baxter/

Examples of Erosion at Public Sites on Nantucket

For this project we selected 4 public locations to highlight three methods of documenting erosion. The locations — Dionis Beach, the Madaket Beach parking lot, Cisco Beach, and Codfish Park — were also researched using the Massachusetts Oceanic Resource Information System (MORIS). The Massachusetts Office of Coastal Zone Management has developed the MORIS to allow the public to view and create maps with information on Massachusetts coastal regions. MORIS, created by the Massachusetts Office of Coastal Zone Management, is a catalog of maps created by the public and the Commonwealth of Massachusetts. This set of maps provides information and imaging of Massachusetts coastal regions.

MORIS also contains historic and current satellite imagery of Nantucket along with built-in measuring tools. This enabled the team to determine erosion rates for the selected areas.

With information from the MORIS system, the research team was able to conclude the following about the historical erosion rates at the four focus areas:

- Dionis Beach has experienced lower levels of erosion, with an estimated erosion rate of 1.5 feet per year since 1970 (MORIS). This has caused the dunes at Dionis beach to be tall and steep, making them less stable and easier to erode.
- Madaket Beach has eroded at an estimated rate of 9 feet per year since 1970, which is the highest rate of the four locations we studied (MORIS). This has caused the parking lot to lose the majority of its area, as well as creating a three-foot drop onto the beach from the lot.
- Cisco Beach has experienced erosion at an estimated rate of 6 ft per year since 1970 (MORIS). This has caused a steeper slope on the beach, as well as creating smaller dunes farther from the high tide line.
- Codfish Park has eroded at an estimated rate of 4 ft per year since 1970 (MORIS). While the erosion rate is lower than some of the other locations, the bluff receding threatens the properties atop of it.

Methodology

The goal of the project was to evaluate the use of various photo capturing technologies to document coastal land, analyze coastal erosion, and develop erosion mitigation proposals for selected public locations to add to Nantucket’s Coastal Resilience Plan. To achieve this goal, the following objectives were identified:

1. Utilize handheld photography, drone photography, and photogrammetry to visually document coastal erosion at specific public locations on Nantucket.
2. Identify changes in coastal erosion at specific public locations on Nantucket.
3. Compare the application of handheld photography, drone photography, and photogrammetry for evaluating coastal erosion.

4. Propose coastal erosion mitigation strategies for specific public locations that build upon existing plans.

Results

Results of Photo Capturing

Through photography and photogrammetry, we were able to document the coastal erosion occurring at Madaket Beach parking lot, Dionis Beach, Codfish Park, Cisco Beach, and Jetties Beach. Documenting the current level of erosion will allow for future comparisons to see whether there has been erosion or accretion over time. Figure 2 displays examples of the drone photography taken of Dionis Beach.

Figure 2. Drone photos taken on Dionis Beach courtesy of Burton "Spruce" Balkind. The Photo was captured at high tide.

Photogrammetry was completed on Dionis and Jetties Beach by Jacob Tinkhauser. Additionally, an example of Sconset Bluff was utilized for analysis that was previously completed by Tinkhauser on June 11, 2023. Figure 3 displays the photogrammetry point cloud of Dionis Beach. Finally, handheld photography was taken at all four locations while on public land.

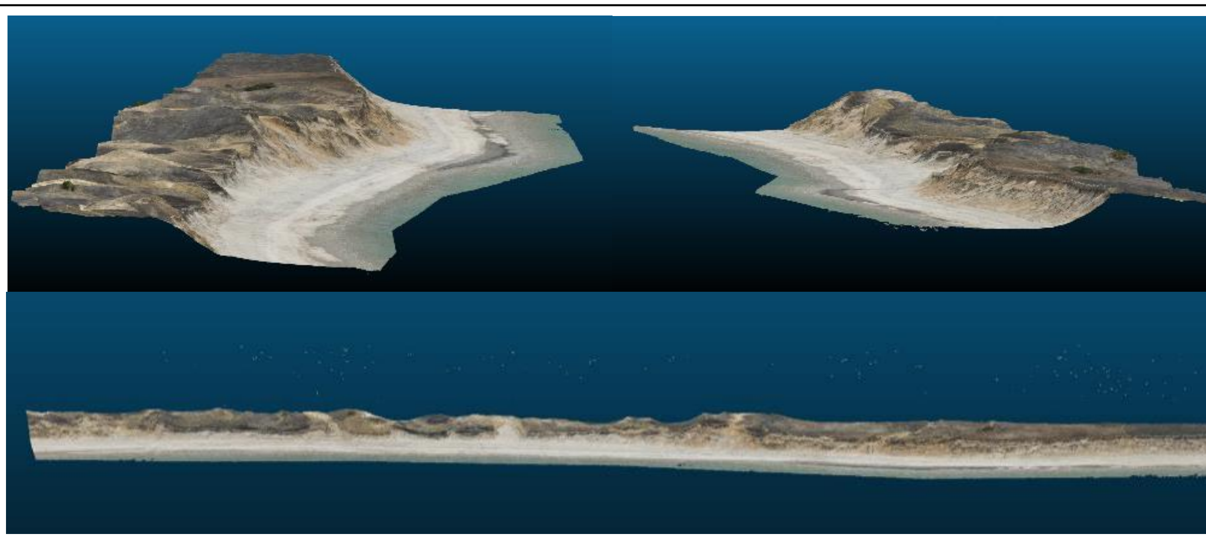

Figure 3. Examples of the Dionis Beach photogrammetry scan completed by Jacob Tinkhauser. This point cloud was completed at low tide.
https://drone.farfetchednantucket.com/

The images taken during research, along with measurements taken within MORIS, demonstrate that changes in erosion are evident at Dionis Beach, Madaket Beach parking lot, Cisco Beach, and Codfish Park. Each of these places have suffered severe damage from erosion in recent years.

Comparing Photo Capturing Technologies

The team has concluded that each of the photo capturing technologies compared has an application in visually documenting coastal erosion, and that none were singularly superior to the others. Photogrammetry point clouds are more useful for analyzing changes in elevation as they can be rotated and viewed freely after capturing. Drone photography is more useful for viewing large stretches of land and areas that are not readily accessible on foot. Handheld photography is more useful for close, detailed views of specific examples of coastal erosion. However, all these technologies can be used in conjunction with each other to allow for more diverse imaging of the coastal erosion in an area. All methods should be utilized frequently, capturing new data at least once per year, to allow for use of the latest data in future reviews. In addition, MORIS provides a comprehensive database of satellite imagery that can be used to view current and historic images of beaches, allowing for coastline recession to be measured.

Recommendations

Dionis Beach

At Dionis beach, sand fencing could be used to help build the dunes on the beach, in addition to creating a new, more gradual grade to the slope. It will also help protect the dunes from people and animals climbing on them and disrupting dune stability. Further planting of vegetation can be used to help build the dunes. Planting at the base of the dunes could help regrade the dunes as they accrete sand, as well as making the dunes more stable through their root systems. Fortunately for Dionis, there are few houses directly on the cliff face, so simply monitoring is an option. Some households may have to relocate, but that would be up to the property owner and done in due time. Some of the dunes are quite high on Dionis, making regrading also a viable option. In combination with vegetation, it could lead to a resilient shoreline.

Madaket Beach Parking Lot

The Madaket Beach parking lot is in a state of disrepair and has a steep drop off at the edge of the lot. A significant portion of the parking lot has already been lost. Monitoring the parking lot to determine if it is doing harm to the beach while continuing to utilize the existing space would be the best solution. Relocating the parking lot is also possible, as the town owns land around Madaket Beach that could be used. Sand fencing would help to build up the sand dunes in the area around the parking lot. This would help slow the current erosion in the area and give more time to apply alternative mitigation methods.

Cisco Beach

At Cisco Beach, vegetation could be used to help to slow down the effects of erosion from smaller waves. This would help stabilize the dunes and allow for accretion. Sand fencing would be effective on Cisco Beach as the dunes are not regularly reached by high tide or storms

(Massachusetts Office of Coastal Zone Management, 2018). Sand fencing would help to capture sand. Further monitoring of Cisco Beach is recommended to continue to assess erosion rates and risks.

Codfish Park

For Codfish Park, relocating the houses on top of the bluff would ensure that the houses are not in danger of falling over the cliff, as well as being the best way to protect the bluff from further erosion. Using beach nourishment would allow for the cliff to become more stable and make the slope more gradual to help slow erosion. This would also allow the houses and road at the top of the slope more time before they would either be moved or be abandoned. Since almost all other methods are impractical at Codfish Park due to the high bluff, we recommend monitoring the beach to get more data or to see if other mitigation methods become viable in the future.

Recommendations for Further Work

The team recommends that more data is collected using the three photo capturing methods, as well as other methods once they become available. Photo capturing should be completed once a year at minimum to allow for more data for comparison for later studies. Additionally, new erosion mitigation installations should be prioritized at Codfish Park and Madaket Beach.

The threat of coastal erosion will not be eliminated by the results of this project; it is a greater issue that cannot be solved with one study. While this project will give Nantucket a framework to use to mitigate erosion, the issue will never fully go away. It is up to the residents of Nantucket and the federal government to protect this island community and the amazing things it holds.

Authorship

Section Name	Author(s)	Editing Author(s)
Abstract	RW	ALL
1.0 Introduction	TC, RW	ALL
2.0 Background	ALL	ALL
2.1 Coastal Erosion	RW	ALL
2.1.1 Wave Action	RW, TC	ALL
2.1.2 Sea Level Rise	RW, TC	ALL
2.2 Erosion on Nantucket	TC	ALL
2.3 Erosion Control Methods	PT	ALL
2.4 Technologies Used for Visual Documentation of Locations	MS	ALL
2.5 Legality	TC	ALL
3.0 Methodology	ALL	ALL
3.1 Visual Documentation of Coastal Erosion	MS	ALL
3.2 Identify Changes in Coastal Erosion at Specific Public Locations	TC, RW	ALL
3.3 Comparison of Usages for Photo Capturing Technology	MS	ALL
3.4 Proposals for Erosion Mitigation at Specific Public Locations	TC, RW	ALL
4.0 Results	ALL	ALL
4.1 Results of Photography and Photogrammetry	MS	ALL
4.2 Results of Identifying Changes in Levels of Coastal Erosion	PT	ALL
4.2.1 Dionis Beach	PT	ALL
4.2.2 Madaket Beach Parking Lot	PT	ALL
4.2.3 Cisco Beach	PT	ALL
4.2.4 Codfish Park	PT	ALL
4.3 Results of Comparing Photo Capturing Technologies	MS	ALL
4.4 Results of Creating Coastal Erosion Mitigation Proposals	RW, PT	ALL
4.4.1 Dionis Beach	PT. RW	ALL
4.4.2 Madaket Beach Parking Lot	PT. RW	ALL
4.4.3 Cisco Beach	PT. RW	ALL
4.4.4 Codfish Park	PT. RW	ALL
4.4.5 Timeline of Recommendations	PT. RW	ALL
5.0 Conclusion & Further Recommendations	TC, MS, RW	ALL
6.0 Summary	TC	ALL
Appendix A: Interview Guide	ALL	ALL
Appendix B: Informed Consent Form	TC	ALL
Appendix C: Photogrammetry Point Cloud Files and Instructions	MS	ALL
Appendix D: Handheld and Drone Photos	RW	ALL

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1.0 Introduction

The island of Nantucket is a result of a glacial moraine, a collection of sediment left behind as a result of glacial movements, that was built upon by tidal action (Hoff, 2021). This geological makeup creates an environment that is much more susceptible to erosion than landmasses with a base of bedrock. With the threat of losing land, houses, business, and government buildings, mitigating coastal erosion is an important issue for the island community.

Nantucket's 2021 Coastal Resilience Plan estimates that by 2070, a total of $3.4 billion in damages will likely be caused by coastal erosion. Additionally, a total of 2,300 buildings on Nantucket are at risk from coastal flooding and erosion, with 50% of those properties being historic. The damage and destruction of these buildings would have major impacts on the lives of many of the residents and property owners on Nantucket, with many of the residents who live along the coast being forced to either abandon or relocate their homes (*Coastal Resilience Plan | Nantucket, MA – Official Website*, n.d.). Locations such as the Steamship Authority terminal and the Hy-line Cruises terminal are also at risk according to the Coastal Resilience plan; both of these locations are critical for transporting residents, tourists, and goods to and from the island. An increase in coastal erosion at the docks, coupled with sea level rise, could delay, or prevent travelers and the supply of goods from reaching the island (*Coastal Resilience Plan | Nantucket, MA – Official Website*, n.d.).

This increased threat posed by erosion has led to erosion mitigation becoming an important topic for the Nantucket community. As shown in Figure 1, coastal erosion mitigation structures, such as jetties, groynes, sand fencing, vegetation, and geotubes have been built to help protect the Nantucket shoreline. These structures are designed to help with sand accretion, reduce the damage caused by waves, or both.

Figure 1. Erosion Control Structures: **L**: Jetty at Jetties Beach
C: Sand fencing and vegetation at Madaket Beach **R**: Geotubes at Sconset Beach
https://www.savenantucketbeaches.org/

Past efforts have been made to catalog the mitigation efforts on Nantucket's beaches; a study was conducted by Worcester Polytechnic Institute in 2014 that utilized a combination of photography and written descriptions to document the coastal erosion mitigation structures on Nantucket's beaches. This information was then used to determine the condition of selected erosion control structures, as well as the levels of erosion that occurred in the surrounding areas (Hunt et al., 2014). Each structure was then graded on a scale of 0-6 where a rank of 5-6 indicated that the structure is effective, while a 3-4 meant that the structure is considered adequate, and anything below a 3 meant the structure is ineffective. Proposals for coastal erosion mitigation plans were then formed based on those ratings (Hunt et al., 2014).

The goal of this project was to evaluate the use of various photo capturing technologies to document coastal land, analyze coastal erosion, and develop erosion mitigation proposals for selected public coastal locations to add to Nantucket's Coastal Resilience Plan. The photo capturing technologies used were handheld photography, drone photography, and photogrammetry scanning. Once data was collected, an analysis of the photographic data was performed at each of the chosen locations. Subsequently, the different visual capture technologies were compared with each other, and their relative advantages and disadvantages documented. Finally, proposals for mitigating coastal erosion were developed for each location studied based on the photographic data and case studies of similar locations. These proposals were written to build on ideas already included in the Coastal Resilience Plan.

Section 2 of this report summarizes background information on coastal erosion, erosion mitigation, and the photo capturing technologies used in this study. Section 3 describes the goal and objectives of this project and the methods used to execute the project. Section 4 presents the team's results and findings from completing the research objectives. Finally, Section 5 provides conclusions as well as recommendations for how future research can build upon this project.

2.0 Background

Coastal erosion and coastal erosion mitigation are complex issues. For this reason, this section presents a short review of existing literature on coastal erosion, coastal erosion on Nantucket, coastal erosion mitigation, and visual documentation technologies.

2.1 Coastal Erosion

Erosion is the natural process of soil, rocks, and land being worn down by natural forces such as water and wind (U.S. Climate Resilience Toolkit, 2021). Shorelines that are constantly exposed to waves and high winds, along with other weather events, can be impacted more harshly compared to other areas. This occurs slowly overtime due to the movement of sediments and may result in the reduction of the shoreline (U.S. Climate Resilience Toolkit, 2021).

2.1.1 Wave Action

As shown in Figure 2 and Figure 3 (following page), there are two types of waves that impact the shorelines: constructive and destructive waves. Constructive waves are small, low-energy waves that push natural materials inland and help build up the shoreline (Geological Survey Ireland, n.d.). Destructive waves, high-energy waves with strong back washes, take material away from the shoreline. Destructive waves are more common and stronger during storms, when tides and intense winds cause the waves to grow (Geological Survey Ireland, n.d.). The pattern of constructive and destructive waves creates a shoreline that gradually shifts, building and destroying as time goes on.

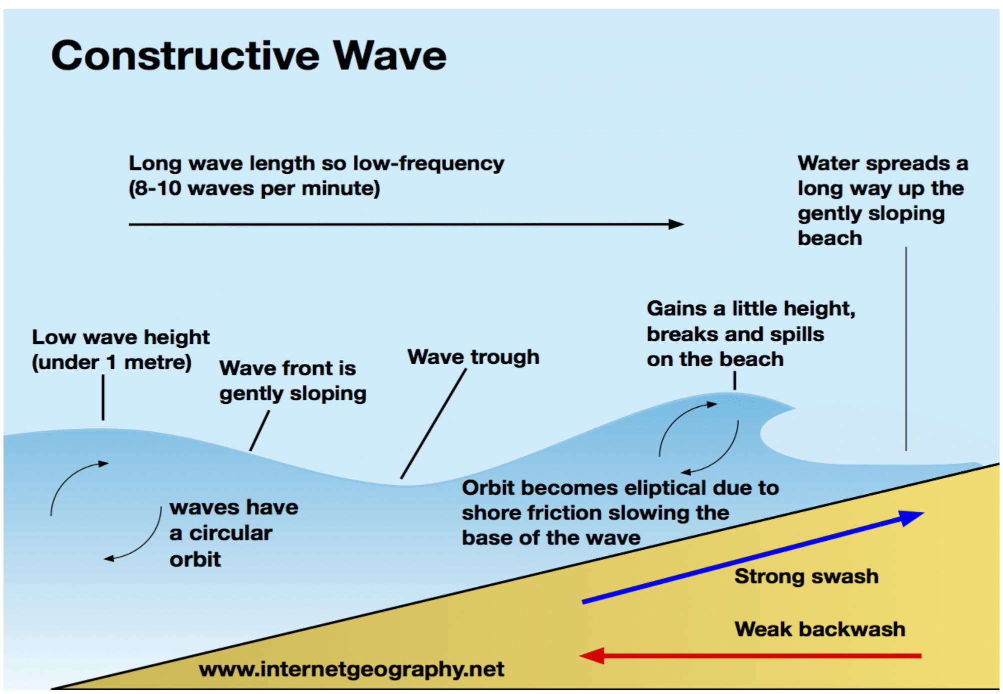

Figure 2. Additive effect of constructive waves on beaches.

Constructive Waves. (n.d.). Internet Geography.
Retrieved November 6, 2023, from https://www.internetgeography.net/topics/constructive-waves/

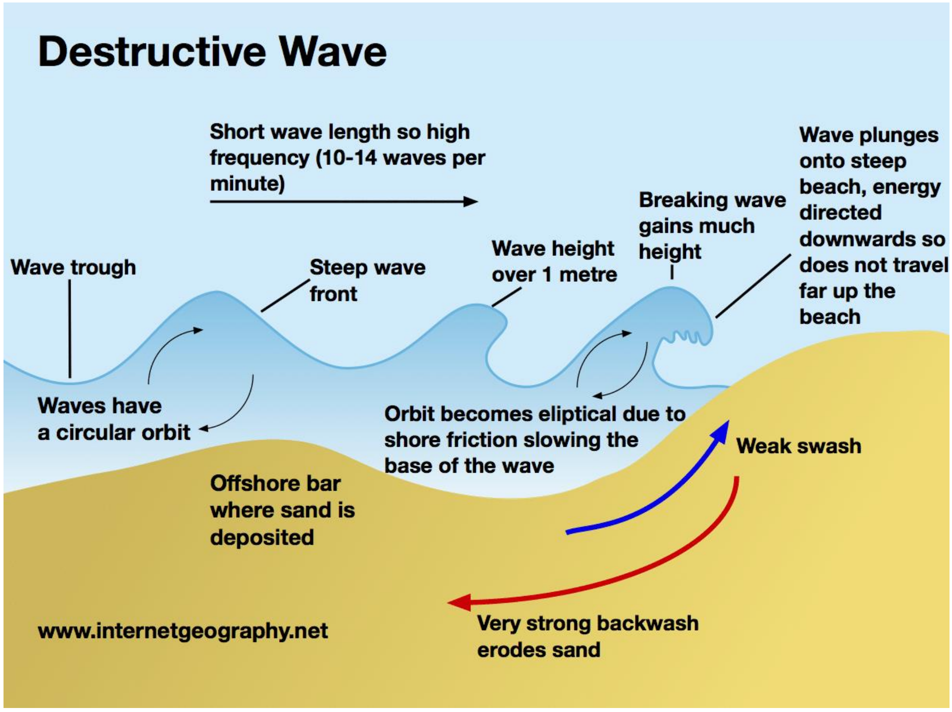

Figure 3. Diminutive effect of destructive waves on beaches.

Destructive Waves. (n.d.). Internet Geography.

Retrieved November 6, 2023, from https://www.internetgeography.net/topics/destructive-waves/

2.1.2 Sea Level Rise

The rise in global temperatures resulting from climate change is causing ocean levels to rise. This is occurring as a direct result of the melting of ice sheets and glaciers, as well as the thermal expansion of the water in the ocean (NASA, n.d.). This rise in sea level means that the damage that can be done from coastal erosion is growing; the higher sea level means that the ocean water can reach farther inland, causing more erosion and damage to property. The increase in global temperatures will cause an average increase in sea levels of up to 6.6 feet between the years 2000 and 2100 (Environmental Protection Agency, n.d.; *Sea Level Rise Technical Report*, 2022). Additionally, it is common for some places to experience up to 25 or even 50 feet of coastline recession every year (U.S. Climate Resilience Toolkit, 2021). On average, the south side of Nantucket loses 2.2 feet of shoreline per year, with some areas losing as much as 12 feet of shoreline per year (*State of the Beach/State Reports/MA/Beach Erosion*, 2015).

Another important factor in coastal erosion is storms. Climate change has caused more frequent and more violent weather events to occur, resulting in storms that have a greater impact on the erosion of shorelines globally (Perkins, 2010). Strong winds, violent waves, and higher-than-normal tides can damage shorelines. Large weather events, such as hurricanes and floods, can have an extreme and sudden impact. During a single intense storm, up to one year's worth of erosion can occur (Perkins, 2010).

2.2 Erosion on Nantucket

Nantucket has worked to mitigate coastal erosion for a long time. The island's beaches are constantly changed by the wind and waves. However, in the past few decades, this problem has been causing more frequent and heavier damage to some of the properties closer to the coast on Nantucket. In the past, residents of the island would move the affected buildings inland as the primary method of combating coastal erosion (Erosion Overview, n.d.). However, moving a building can be both cost and labor intensive, and does nothing to combat the continued degradation of the shoreline. The only alternative to relocating buildings was to allow the structure to succumb to the sea, though this can cause additional damage to Nantucket's beaches and may also result in polluting the surrounding waters. Therefore, Nantucket has attempted to implement various coastal erosion mitigation methods to slow the effects of erosion.

Some of the earlier erosion mitigation methods employed by Nantucket were hard erosion control structures. Hard structures are solid structures that are usually made of rock, concrete, or other solid materials and are typically more permanent installations. While the first installation of a hard structure on Nantucket is not currently known, the last time they were legally allowed to be installed on the island was 1978. At this time, a new bylaw was passed by the Commonwealth of Massachusetts that prevented the creation of any new hard structures in Massachusetts (Erosion Overview, n.d.). Any hard structures created before this time were allowed to still exist and could be repaired and maintained. The Massachusetts Legislature passed legislation making it illegal to alter any beach or coastal wetland (Mass. General Law Chapter 131, Sec. 40). This included the changing of the beach itself or structures built upon it. The law does, however, allow for the conservation committees of towns and the state to allow for certain projects to still be carried out. Additionally, this law has been amended several times since its original conception. As of April 4th, 2008, no new structures of any kind could be created on any town property on the eastern coast of Nantucket. This includes all hard and soft erosion control methods (Nantucket Bylaws Ch.67, 2008). This occurred as a direct result of a referendum started by a group of Nantucket citizens called the Coalition for Responsible Coastal Management. This group had concerns about how the beach nourishment being proposed would affect the local fishing grounds. Residents of Nantucket voted overwhelmingly against the beach nourishment effort and in favor of the moratorium (Erisman, 2014). Like the original law, these structures can be maintained or replaced with the permission of the landowner where the structure is present, if they were created before the moratorium was put into place. This ban was eventually lifted on December 31, 2013 (Nantucket Bylaws Ch.67, 2008).

Other efforts have focused on measuring the levels of coastal erosion. This allows the scientific and governmental bodies in Nantucket to measure the rate at which the coasts are diminishing, which can then be used to determine if the rate of erosion has changed over time. This has been determined in several different ways on Nantucket over the years, including the use of physical marking implements, such as stakes, and satellite-based Geographic Information Systems (GIS). Nantucket started the Coastal Monitoring Project in late 2021 which utilized sets of two stakes, called stations, placed in 20-foot increments away from the shoreline. A total of 13 stations have been installed since the beginning of the project, starting with a station each at Nonantum Ave and Tom Nevers field on November 11th, 2021. The map in Figure 4 showcases all the locations where the stations were installed.

Figure 4. A map showcasing the eight locations where the level of erosion over time was measured on Nantucket.

https://www.nantucket-ma.gov/2628/Coastal-Monitoring-Project

While measurements are still being taken due to the recent nature of the project, significant amounts of shoreline have already been lost in Nantucket's vulnerable locations. As of September 19, 2023, two of the sewer bed marking stations have recorded the greatest amount of erosion at 53 feet and 55 feet, respectively. However, this method of using marking stakes has had problems with vandalism since its inception; several of the locations have been abandoned due to the outermost markers being vandalized. So, while markers are effective at visualizing and measuring the effects of coastal erosion, this information can be lost if the stakes are damaged by storms or vandalism (*Coastal Monitoring Project | Nantucket, MA - Official Website*, 2023).

Meanwhile, another method Nantucket has utilized to measure the effects of coastal erosion is through satellite-based GIS systems. As of September 3, 2020, the Federal Emergency Management Agency (FEMA) released a coastal erosion study for Nantucket, as well as including an existing GIS map that identified the locations on Nantucket that are at greater risk of coastal erosion. This provides several different scenarios based on the predicted rise of the sea level by a specified year, and marks areas that will likely be damaged by the changing shoreline. While this map does adequately predict the future effects of coastal erosion on Nantucket, it does not provide information on how Nantucket has been affected by coastal erosion in the past.

Additionally, while a study was completed by FEMA as recently as 2020, the data in the GIS system is from a study in 2012 and likely does not display predictions based on the current levels of climate change (*FEMA Coastal Erosion Hazard Map | Nantucket, MA - Official Website*, 2020).

2.3 Erosion Control Methods

Two types of erosion control in use on Nantucket are hard structures and soft structures. As stated in Section 2.2, hard structures are usually made of rock, concrete, or other solid materials. Whereas soft structures are impermanent solutions, like sand fencing, that are often more environmentally friendly than hard solutions. Both types of structures can prove effective in the proper circumstances, but both also have their drawbacks. Properly installed erosion control structures are one of the main defenses against continuing coastal erosion.

The most common types of hard structures are groynes, jetties, seawalls, revetments, bulkheads, breakwaters, and geotubes (*Geotubes*, n.d.; U.S. National Park Service, n.d.). Jetties (Figure 1) and groynes are similar structures that are both built perpendicular from the shore (U.S. National Park Service, n.d.). Seawalls, bulkheads, and revetments are all structures that are parallel to the shore. Seawalls are walls built in the ocean to prevent erosion by having waves hit a cement structure instead of the land. Bulkheads are similar structures that also are walls that are meant to take the force of the waves, but do not keep added sediment (U.S. National Park Service, n.d.). Revetments are sloped solid structures that help absorb the force of the waves. Breakwaters are structures built in the water that slow the force of the wave before it hits the beach. (Britannica, n.d.). Finally, geotubes are large, long sandbags which provide a barrier that acts like the beach itself (U.S. National Park Service, n.d.). This helps to protect the sand behind them from erosion by blocking the water from oncoming waves (Figure 1).

Soft structures are starting to be used more than hard structures for erosion control as they are thought to be better for the environment. The main types of soft structures include beach nourishment, sand fencing, and vegetation. Beach nourishment is the process of adding more sand to beaches to rebuild the lost sediment due to erosion (*Massachusetts Department of Environmental Protection | Mass.gov*, n.d.). This helps restore the beach closer to its original condition and push back the effects of erosion. Sand fencing helps to slow down wind and trap sand, which helps to build up sand around them. This can help to build the beach up and slow down the loss of sand from the beach. Vegetation planted on beaches can help to keep the sand in place as the roots make the ground more solid. The roots hold the sand in place better and provide protection for the sand against the wind and waves. Beach nourishment, vegetation, and sand fencing can be more effective when used together. Soft structures try to mimic the beach itself and help to avoid some of the negative impacts that hard structures have on beaches and coastlines. They try to work with the existing beach instead of trying to catch sand and move it against the natural flow of the ocean.

For soft structures, the concerns tend to focus more on upkeep rather than erosion. Beach nourishment does fix the problem in the short term, but it does not solve the problem. The sand will continue to be eroded away in the future. Because of this, beaches need to be renourished every few years (U.S. Army Engineer Institute for Water Resources, n.d.). This is a problem as beach nourishment is expensive and needs to be entirely redone regularly every three to five years. This leads to concerns about upkeep, as without constant addition of sand, the problem will continue to get worse. Beach nourishment in conjunction with vegetation and sand fencing can help to limit these problems and make the beach more resilient. For sand fencing, one problem is that it can get buried over time and become less useful if not properly maintained. Sand fencing can also catch debris and garbage that can be harmful to the beach and people around the fencing (*Massachusetts Office of Coastal Zone Management (CZM) | Mass.gov*, n.d.). Vegetation provides the positive benefit of not only helping to keep sand in place, but also not needing as much upkeep as other methods. These plants are often already growing on the beach naturally and helping to limit erosion. Since these plants naturally grow on the coast, it is easy to plant and grow additional vegetation to further decrease the impacts of erosion (Commonwealth of Massachusetts, n.d.).

Regrading is another form of erosion control where the shape of a sand dune is altered to reduce the damage done from erosion. Through this method, the slope will be altered to be at a shallower angle. Additionally, regraded beaches are better at retaining vegetation that has been planted (*TRPA BMP Handbook*, 2014).

There are many ways to try and slow the effects of erosion. These methods vary in price, effectiveness, and maintenance required. They all, under certain circumstances, can be somewhat effective, but some of the methods are more effective than others at limiting erosion. Soft structures are believed to be better at limiting erosion than hard structures (New York State Department of Environmental Conservation, n.d. Beach nourishment, vegetation, and sand fencing are all effective methods of erosion control that are inexpensive compared to hard structures.

2.4 Technologies Used for Visual Documentation of Locations

Drone photography which is the process of taking aerial photos of an area using a camera that is either built into or mounted to an aerial drone (Schwindt et al., n.d.). An advantage of drone photography is that some drones can use GPS tracking to mark pre-planned waypoints that the drone will then fly between. Using this, the drone no longer needs to be manually piloted between points and can produce more precise footage (Murphy, 2023). While drone photography allows for camera angles and shots that are not possible on foot, it has other limitations. Due to their limited payload weight, aerial drones typically cannot carry larger and higher quality cameras. More expensive drones with higher payload compacities must be used to achieve the same level of image quality as handheld photography. Weather conditions can make it impossible to get a clear photo or even fly drones. On top of this, some commercial drones frequently only have enough battery life for 30 minutes of flight time. While the battery can be swapped out, this limits how long a flight can last (Schwindt et al., n.d.).

Photogrammetry is the process of using specialized software, like Agisoft Metashape or OpenDroneMap, to analyze a set of photographs taken from a single camera (usually mounted on an aerial drone) as it rotates around an object or area and recreating a 3D representation of the photos' subject. This 3D representation is called a point cloud. The point cloud is made up of floating, colored squares or circles to give the illusion of a full 3D object. The point cloud differs in functionality from the base photo set since when imported into special software, like CloudCompare or Potree, it can be moved or rotated allowing for more viewing angles than the photos provide (Baqersad et al., 2017). Figure 5 showcases how when zoomed out a point cloud appears like a 3D object, but zoomed in reveals the series of floating, colored squares.

Figure 5. Point cloud of Sconset Bluff in Potree **L:** Sconset Bluff point cloud zoomed out
R: Sconset Bluff point cloud zoomed in (visible square points)

https://drone.farfetchednantucket.com/examples/baxter/

2.5 Legality

To legally capture photos of private property, including beaches, all pictures must be taken from either public land or public airspace. According to the Massachusetts Colonial Ordinances of 1641-1647, private property on the coasts is considered to extend to the low tide mark, or the lowest point the shoreline reaches on average. This indicates that large stretches of Nantucket's beaches are considered private property and cannot legally be photographed while standing above the low water mark. As a result, only locations owned by the Nantucket government and conservation organizations, such as the Nantucket Land Bank and the Nantucket Conservation Foundation (NCF), can be photographed on land. Additionally, while still considered private property, the intertidal zone of the beaches is open to a limited number of activities for non-property owners. This includes navigating by walking or the use of a vehicle, fishing, and hunting. Any other activities require the written permission of the landowner. As a result, photography cannot be completed from any point on the beach and must be taken from either a nearby public property or past the low tide mark using a drone or boat (*Public Rights Along the Shoreline | Mass.Gov*, n.d.). According to the Federal Aviation Administration (FAA), it is required for drone operators taking publicly distributed photos to have a Remote Pilot Certificate. Project sponsor Burton Balkind had this certification at the time of the project.

Another legal consideration with the analysis of erosion on private land is the possibility of defamation. Considering the large number of private beaches on Nantucket, negative descriptions of the beaches may be considered libel by the property owner. One impact could be if the property had installed coastal erosion structures, negative descriptions might risk a loss of property value. As a result, the descriptions must be limited to publicly owned areas. Additionally, any descriptions of the erosion in privately owned areas should be presented neutrally (*Public Rights Along the Shoreline | Mass.Gov*, n.d.).

3.0 Methodology

The goal of this project was to evaluate the use of various photo capturing technologies to document coastal land, analyze coastal erosion, and develop erosion mitigation proposals for selected public locations to add to Nantucket's Coastal Resilience Plan. To achieve this goal, the following objectives were identified:

1. Utilize handheld photography, drone photography, and photogrammetry to visually document coastal erosion at specific public locations on Nantucket.
2. Identify changes in coastal erosion at specific public locations on Nantucket.
3. Compare the application of handheld photography, drone photography, and photogrammetry for evaluating coastal erosion.
4. Propose coastal erosion mitigation strategies for specific public locations that build upon existing plans.

3.1 Visual Documentation of Coastal Erosion

To visually document coastal erosion on Nantucket the team utilized handheld digital photography as well as drone photography. Handheld photography was utilized when both physically and legally possible. A combination of smartphone and DSLR cameras were used to document the coastal erosion in this scenario. Additionally, drone photography was utilized to capture locations that handheld photography could not. Figure 6 shows an example of drone photography which was done when public land access was not available. These photographs provided a detailed look at the erosion structures and coasts. Drone photography also allowed for wider shots of the coast that could not be captured when standing on the coast. This allowed for overall erosion of the coast to be viewed.

Figure 6. The picture above shows an example of drone photography, courtesy of Burton Balkind. The picture displays a wooden bulkhead installed at a house near Pimney's Point.

In addition to handheld and drone photography, photogrammetry was used to create three-dimensional representations of the beaches and surrounding areas affected by coastal erosion. Shapefiles marking public beaches owned by either the town of Nantucket, the Land Bank, and Nantucket Conservation Foundation (NCF) were given to Jacob Tinkhauser. These shapefiles specified paths for a drone to fly to capture the photography required to create 3D point clouds of the locations (Baqersad et al., 2017; Murphy, 2023). Figure 7 displays an example of a point cloud, which photogrammetry produces. Using 3D visualization software, like Potree, the point cloud can be rotated and viewed from all angles to give a different visualization than just photography can provide (Baqersad et al., 2017).

Figure 7. An example of a completed point cloud using photogrammetry from the open-source website Potree.
https://potree.org/potree/examples/viewer.html

3.2 Identify Changes in Coastal Erosion at Specific Public Locations

To identify the changes in coastal erosion, the team surveyed the Madaket Beach Parking Lot, Dionis Beach, Codfish Park, Cisco Beach, Jetties Beach. This was achieved through comparing past and current visualizations of each location, to historic maps and photographs from the Town of Nantucket GIS system and the Massachusetts Ocean Resource Information System (MORIS). Figure 8 (following page) displays the MORIS system which has many different maps on previous erosion and on future projections of coastal flooding. The MORIS maps were used to project the rate at which each beach would erode. Additionally, visual comparisons were completed by noting the changes between current photographs and the photographs taken during the 2014 WPI study. Figure 9 (following page) displays an example of a photo taken during the 2014 study. Each photo was taken at the same tide to ensure that the comparisons would be accurate between the two time periods. Both the erosion rates and visual comparisons can be used to improve the current coastal erosion analysis methods.

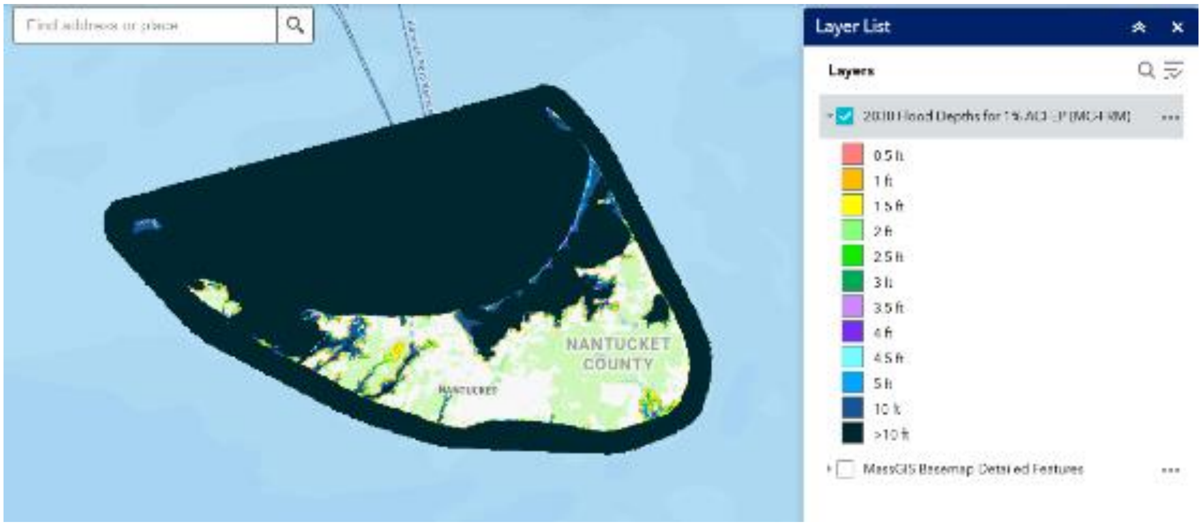

Figure 8. An example of the MORIS system map that shows the depth of water on the island of a flood with a 1 percent chance of happening in the year 2030.
https://czm-moris-mass-eoeea.hub.arcgis.com/#DataViewer

Figure 9. An example of the geotubes on Siasconset Beach from the WPI 2014 project.
https://wp.wpi.edu/nantucket/projects/2014-projects/erosion/

3.3 Comparison of Usages for Photo Capturing Technology

Handheld photography, drone photography, and photogrammetry each have applications where they are better utilized than the others. To determine which technology may be better suited for different scenarios the research team created a table of advantages and disadvantages for each technology. A list of attributes for the four chosen areas was then created based on the advantages and disadvantages. The listed attributes were then utilized to determine which technology would be most effective at analyzing each location using factors such as terrain and available public land.

3.4 Proposals for Erosion Mitigation at Specific Public Locations

To write a proposal for future coastal erosion mitigation strategies, the team first analyzed the data collected on erosion at the selected public locations. The team first visited each of the areas to better understand how the different areas were being affected. Then, based on the levels of coastal erosion and the attributes of the area, two to three potential plans for mitigation were developed for each location. This was done by using information given to the team by the Nantucket Natural Resource Department and from research on case studies of similar locations. The key goal for these plans was to add information to Nantucket's Coastal Resilience Plan. While the Coastal Resilience document has plans listed for the chosen areas, the team focused on alternative methods to create a wider set of alternative erosion structures. Each of the proposed erosion mitigation methods included a rough timeline for how long they would be effective. This enables the plan to be implemented with a stronger base understanding of the strengths and weaknesses of the available methods.

4.0 Results

This section presents the results from the application of three visual capture technologies in documenting public land on Nantucket. We then showcase the analysis of coastal erosion for Dionis Beach, Madaket Beach Parking Lot, Cisco Beach, and Codfish Park. Next, the strengths and weaknesses of each of the three photo capturing technologies were compared to determine how they should be utilized in the future. Finally, this section shares the team's proposed coastal erosion mitigation methods for the four locations.

4.1 Results of Photography and Photogrammetry

Through photography and photogrammetry, we were able to document the coastal erosion occurring at Madaket Beach Parking Lot, Dionis Beach, Codfish Park, Cisco Beach, and Jetties Beach. These public locations were selected after interviews with Leah Hill and Vincent Murphy, of the Town of Nantucket Natural Resource Department. Documenting the level of erosion now will allow for future comparisons to see whether there has been erosion, accretion, or no change over time. Drone photography was taken at both Dionis and Jetties Beach courtesy of island resident Burton "Spruce" Balkind. Figure 10 and Figure 11 (following page) display examples of the drone photography taken on Jetties Beach and Dionis Beach respectively.

Figure 10. Drone photos taken on Jetties Beach courtesy of Burton "Spruce" Balkind. The Photo was captured at high tide.

Figure 11. Drone photos taken on Dionis Beach courtesy of Burton "Spruce" Balkind. The Photo was captured at high tide.

Photogrammetry was completed on Dionis and Jetties Beach by Jacob Tinkhauser. Additionally, an example of Siasconset (Sconset) Bluff was utilized for analysis that was previously completed by Tinkhauser on June 11, 2023. Figures 12-14 (following pages) display the photogrammetry point clouds of Jetties Beach, Dionis Beach, and Sconset Bluff respectively. Finally, handheld photography was taken at all five locations while on public land. Figures 20-23 (Section 4.4) showcase the current levels of beach erosion on Dionis Beach, the Madaket Beach Parking Lot, Codfish Park, and Cisco Beach respectively. Meanwhile, Figure 1 (left) in the Introduction displayed the erosion surrounding the Jetty on Jetties Beach.

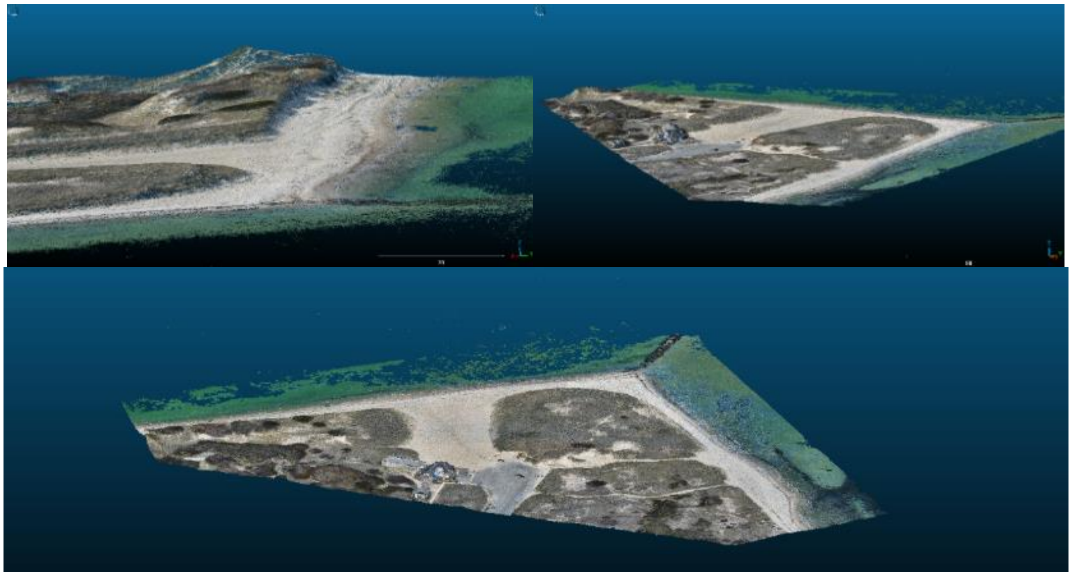

Figure 12. Examples of the Jetties Beach photogrammetry
scan completed by Jacob Tinkhauser. This point cloud was completed at high tide.
https://drone.farfetchednantucket.com/

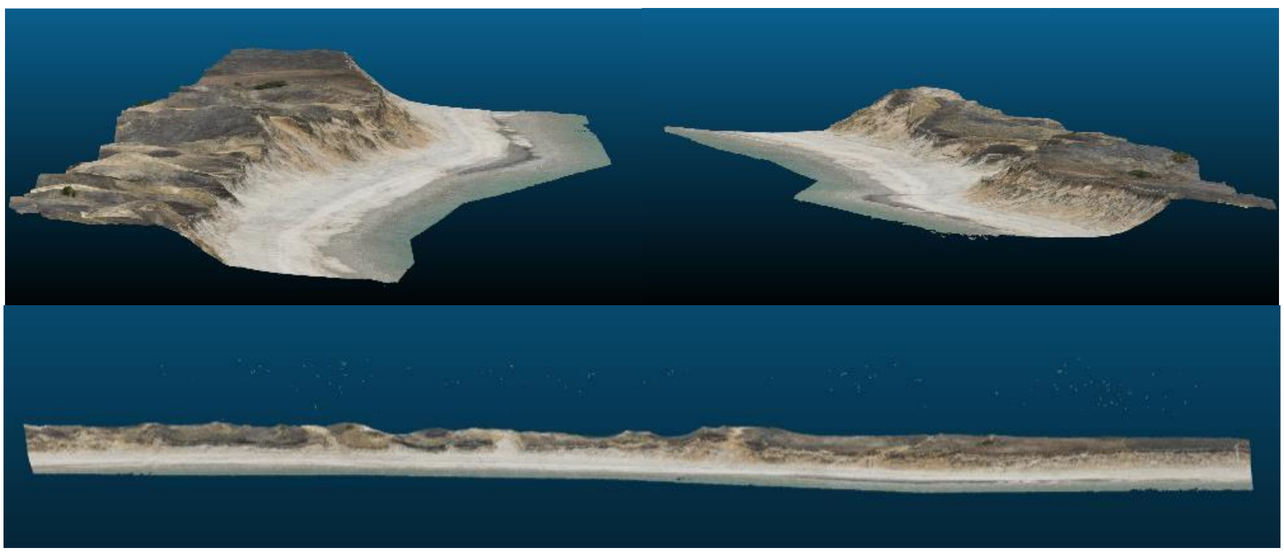

Figure 13. Examples of the Dionis Beach photogrammetry
scan completed by Jacob Tinkhauser. This point cloud was completed at low tide.
https://drone.farfetchednantucket.com/

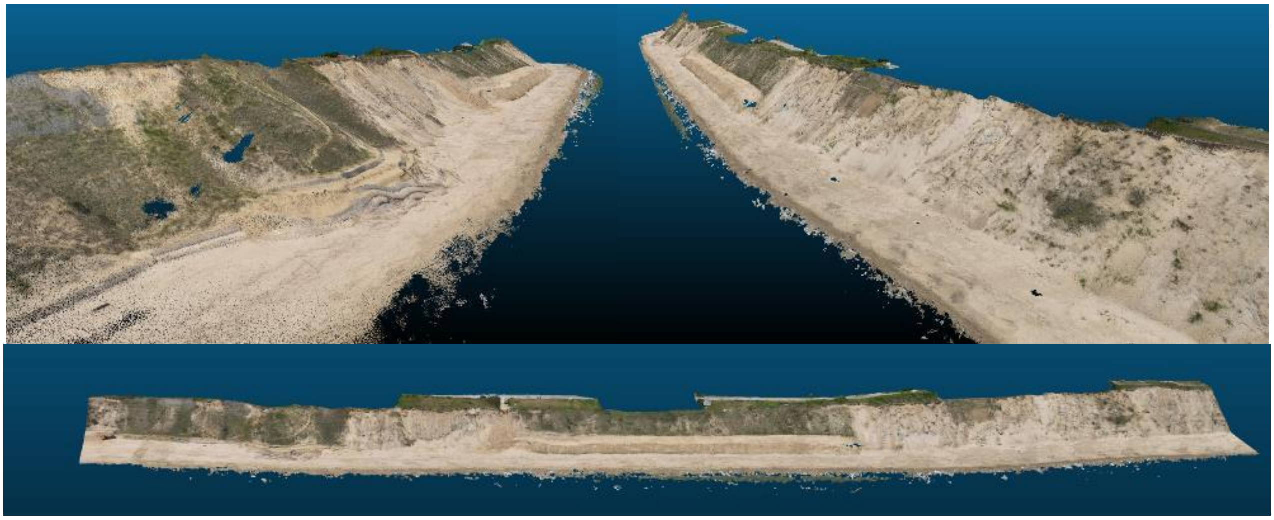

Figure 14. Examples of the Sconset Bluff photogrammetry scan completed by Jacob Tinkhauser. This point cloud was completed at low tide.
https://drone.farfetchednantucket.com/

The download links for the photogrammetry point clouds files, along with instructions on how to view the point clouds are provided in Appendix C. Appendix C additionally contains the links to videos which showcase rotating around the point clouds.

4.2 Results of Identifying Changes in Levels of Coastal Erosion

The images taken during research demonstrate that changes in erosion are evident at Dionis Beach, Madaket Beach Parking Lot, Cisco Beach, and Codfish Park. Each of these places have suffered erosion over recent years. The amount of erosion varies among the beaches due to factors such as whether they are on windward or leeward side of the island and geography of the beach. These levels of erosion were found on the Massachusetts Ocean Resource Information System (MORIS) through the Massachusetts Office of Coastal Zone Management. The system is run by the Massachusetts Executive Office of Energy and Environmental Affairs and has information on the coasts of Massachusetts spanning back to the 1840's. The system has numerous long-term projections on how the coast will change in the future. MORIS also enables users to measure how far coastlines have changed in recent years with the measuring tool inside the software. The measuring tool is calibrated so that even when zoomed in the measurements are still accurate. By switching the map layer that was being used it is possible to see the difference in the two images as the location stays the same when switching the layers. The team utilized these measuring tools to find how far the coastline had moved since the coastline charts had last been updated in 2014. The team also used maps from the Federal Emergency Management Agency (FEMA). The FEMA maps have similar features to that of the MORIS maps. The team also used the measurement tool that is built into the website to measure the high sea level rise scenario. Tables 1, 2, and 3 (following pages) showcase the distance coasts moved inland between differing periods of time at the four locations analyzed.

Table 1. Erosion Data From 1970 to 2014

Location	Amount of erosion 1970 to 2014	Rate of erosion per year
Dionis Beach	• ~66 feet	• ~1.5 feet
Madaket Beach Parking Lot	• ~396 feet	• ~9 feet
Cisco Beach	• ~264 feet	• ~6 feet
Codfish Park	• ~180 feet	• ~4 feet

https://czm-moris-mass-eoeea.hub.arcgis.com/
Created using MORIS Measurement Tool

Table 2. Erosion Data From 1840's to 2014

Location	Amount of erosion 1840's to 2014	Rate of erosion per year
Dionis Beach	• ~340 feet	• ~2 feet
Madaket Beach Parking Lot	• ~1870 feet	• ~11 feet
Cisco Beach	• ~1140 feet	• ~8 feet
Codfish Park	• ~174 feet	• ~1 feet

https://czm-moris-mass-eoeea.hub.arcgis.com/
Created using MORIS Measurement Tool

Table 3. Erosion Data From 2014 to 2021

Location	Amount of erosion 2014 to 2021	Rate of erosion per year
Dionis Beach	• ~30 feet	• ~4 feet
Madaket Beach Parking Lot	• ~40 feet	• ~6 feet
Cisco Beach	• ~50 feet	• ~7 feet
Codfish Park	• ~10 feet	• ~1.5 feet

https://czm-moris-mass-eoeea.hub.arcgis.com/
Created using MORIS Measurement Tool

Additionally, the photos and scans that the team captured will provide a more in-depth look at the coastline for analysis in the future.

4.2.1 Dionis Beach

Dionis Beach is on the western side of the north shore of Nantucket, lying between Washing Pond Beach and 40th Pole Beach. Like much of the north shore, the waves are typically small and low energy. The dunes at the beach are quite tall and lie far back from the high tide line. In the high sea level rise scenario, the coastal boundary could recede by up to 110 feet by 2030, and by 700 feet by 2100 (FEMA). The high sea level rise scenario is a forecast from FEMA that projects how much land will be lost in the future if sea levels rise by 6.6 feet between 2000 and 2100 (*Sea Level Rise Technical Report*, 2022). Property owners could be at risk of losing land, and even houses unless they are raised or moved further away from the beach.

Dionis Beach has changed over time due to erosion and accretion. As seen in Tables 1, 2, and 3 the amount of erosion has changed over time for Dionis Beach but has consistently only had moderate amounts of erosion. This erosion can be seen in Figure 15 (following page) in the red boxes. When comparing the two photographs the bluff has receded since the picture in 2014. Dionis Beach has not experienced as much erosion as other beaches because it does not experience as many strong, high-energy waves.

Figure 15. Dionis Beach erosion from MORIS:
L: Dionis Beach in 2014 **R**: Dionis Beach in 2021
https://czm-moris-mass-eoeea.hub.arcgis.com/#DataViewer

4.2.2 Madaket Beach Parking Lot

The Madaket Beach Parking Lot is located on the southwestern part of the island. This part of the island experiences large waves during storms which causes large amounts of erosion. This can be seen as the parking lot has been eroded by storms and is now a steep drop off. In the high sea level rise scenario, the coastal boundary could recede by up to around 300 feet by 2030, and 1,700 feet by 2100 (FEMA).

The Madaket Beach Parking Lot has experienced large amounts of erosion over time. This can be seen in Tables 1, 2, and 3 where it has consistently had one of the highest erosion rates of the four locations. This erosion can also be seen in Figure 16 where the parking lot in the red box has visibly eroded over that period. The parking lot has been about cut in half in size in the last 7 years. The house to the left of the parking lot has had its backyard significantly eroded away and is almost on the beach. The Madaket Beach Parking Lot has experienced a large amount of erosion due to the strong waves that the beach consistently has.

Figure 16. Madaket Beach Parking Lot erosion from MORIS:
L: Madaket Beach Parking Lot in 2014 **R**: Madaket Beach Parking Lot in 2021
https://czm-moris-mass-eoeea.hub.arcgis.com/#DataViewer

4.2.3 Cisco Beach

Cisco Beach is located on the southwestern side of the island between Madaket Beach and Ladies Beach. Cisco Beach experiences strong waves, but the dunes are set far back from the high tide line. In the high sea level rise scenario, the coastal boundary could be receded by as much as 200 feet by 2030, and 1,100 feet by 2100 (MORIS). Cisco Beach has seen much erosion in recent years with the banks of the beach and end of Hummock Pond Road being heavily eroded.

Cisco Beach has historically faced large amounts of erosion over time. This can be seen in Tables 1, 2, and 3 where the erosion rates are second to only Madaket Beach. In Figure 17 (following page) the bluffs have been noticeably moved back due to erosion. In the red box erosion has noticeably eroded the bluff away to the point where there is no bluff between the beach and Hummock Pond. Hummock Pond Road in the red box has also been partially eroded away. The large amounts of erosion are due to the beach being on the southern side of the island which experiences stronger waves compared to the northern part of the island.

Figure 17: Cisco Beach erosion from MORIS:
L: Cisco Beach in 2014 **R**: Cisco Beach in 2021
https://czm-moris-mass-eoeea.hub.arcgis.com/#DataViewer

4.2.4 Codfish Park

Codfish Park is located on the eastern side of the island close to Siasconset Beach. This side of the island experiences strong waves that can cause large amounts of erosion. The slope is set close to the water and during high tide water can reach the bottom of the slope. The slope is very exposed to the ocean and is experiencing erosion constantly. As shown in the high sea level rise scenario, the coastal boundary could recede by up to 60 feet by 2030, and 500 feet by 2100 (MORIS).

Codfish Park has faced periods of erosion and accretion over time but is generally eroding overall. This can be seen in Tables 1, 2, and 3 where the beach has consistently been losing land. This erosion can be seen in Figure 18 (following page) where the bluffs have been moved back by erosion. The red box highlights how bluffs have slightly receded since the 2014 scan was taken. In the time since 2014 vegetation has been added to the slope causing the slope to have more brown color than before. The increase in vegetation may be having a positive effect as the erosion is hard to see from the scans and has been less than the average of the previous 44 years.

Figure 18. Codfish Park erosion from MORIS:
L: Codfish Park in 2014 **R**: Codfish Park in 2021
https://czm-moris-mass-eoeea.hub.arcgis.com/#DataViewer

4.3 Results of Comparing Photo Capturing Technologies

Table 4 (following page) features the advantages and disadvantages table comparing handheld photography, drone photography, and photogrammetry.

Table 4. Advantages and Disadvantages of Photo Capturing Technologies

Photo Capture Technology	Advantages	Disadvantages
Handheld Photography	• Close-up detail • More cost effective since a drone is not required to carry the camera • Smaller files	• Viewing angles limited to when the photos were captured • Can only capture photos from locations where standing is physically possible or legally permissible
Drone Photography	• Aerial view • Smaller files • Can access locations that handheld photography cannot	• Detailed photos require a more expensive and robust drone than handheld photography • Viewing angles limited to when the photos were captured • Drone cannot be flown during heavy rain or strong winds • Requires a Remote Pilot Certificate
Photogrammetry	• Viewing angles can differ from when the photos were captured, which can be used to better visualize changes in elevation • Aerial view • Can access locations that handheld photography cannot	• Detail of point clouds is limited by input photography quality and the processing power of the computer used to generate the point cloud • Larger files • Specialized software required for viewing • Drone cannot be flown during heavy rain or strong winds • Requires a Remote Pilot Certificate

Based on the advantages and disadvantages for each technology, handheld photography is recommended at locations where a close, highly detailed view is required. This is because handheld photography generally allows for a higher resolution view of specific, smaller areas than drone photography or photogrammetry. When an area is not accessible or is too large to be captured by handheld photography, then drone photography is suggested for use. This is because drone photography can readily capture wide-area, aerial views. If a 3D representation of a larger area or land formation is needed, then the suggested technology to use is photogrammetry.

Photogrammetry allows for easier viewing of elevation differences because the point clouds generated are rendered in three dimensions and can be rotated.

4.4 Results of Creating Coastal Erosion Mitigation Proposals

This section contains the proposals for coastal erosion mitigation at the chosen public locations. Additionally, Section 4.4.5 discusses the estimated timeline for each of the mitigation methods.

4.4.1 Dionis Beach

Figure 19 shows an example of the erosion occurring on Dionis Beach.

Figure 19. An example of the erosion on Dionis Beach. The photo was captured during mid tide.
Photograph by Ryan Waters

The following are the recommendations that were made:

1. Sand fencing
    a. Sand fencing could be used to help build the dunes on the beach, in addition to creating a new, more gradual grade to the slope. This could also be helpful to keep the vegetation on the dunes intact and to prevent people from going onto the dunes. Depending on the length of the fencing and what type of fencing style is used, the installation of fencing could take three months to a year. The fencing would need to be upkept frequently with replacement and disposal of broken fencing as well as moving the fencing on top of the accreted sand.
2. Vegetation
    a. Further planting of vegetation can be used to help build the dunes. The beach has ample space to allow for more vegetation to be planted. Planting at the base of the dunes could help regrade the dunes as they accrete sand. This would help to

protect the dunes from strong waves in the future and make the slope more resilient.

3. Monitoring
    a. Fortunately for Dionis, there are few houses directly on the cliff face, so letting erosion take its course is an option. Some households may have to relocate, but that would be up to the property owner and done in due time. This is the easiest of the solutions as it requires only reviewing the area every year or so or after storms. short term. In the future if the problem continues to get worse different methods could be implemented.
4. Regrade
    a. Some of the dunes are quite high on Dionis. While it would be labor intensive and costly, regrading is a viable option. While this does take away part of the cliff and result in loss of some of the land it makes the slope less vulnerable to collapse. Taking sand off the top of the dunes and pushing it into the beach would act as a form of beach nourishment. And in combination with vegetation, it could lead to a strong shoreline.

4.4.2 Madaket Beach Parking Lot

Figure 20 shows an example of the erosion occurring at the Madaket Beach Parking Lot.

Figure 20: An example of the erosion at the Madaket Beach parking plot. The photo was captured during high tide.
Photograph by Ryan Waters

As a result, the following recommendation were made:

1. Monitoring
    a. The Madaket Beach Parking Lot is in a state of disrepair and has a steep drop off at the edge of the lot. A significant portion of the parking lot has already been

lost. Monitoring the parking lot to see if it is still useable, while continuing to utilize the existing space would likely be the best solution.

2. Retreat
    a. Relocating the parking lot would require the town of Nantucket to select a new location. There are areas owned by the town near the Madaket Beach Parking Lot that could possibly be used. At Cisco Beach there is a similar situation where the parking lot has been relocated to an area that is slightly further away from the beach. (Graziadei, 2023). The parking lot in its current state is not very big and cannot accommodate more than a few cars at a time, so even a small parking lot would be an improvement. A retreat would allow the current parking lot to erode at its current rate and be used until it is no longer usable.
3. Fencing
    a. The sand fencing would help to build up the sand dunes in the area around the parking lot. This would help to slow some of the effects of erosion and help the parking lot from being further eroded. Waves also do not frequently reach the level of the parking lot so sand fencing would be an effective tool. However, it is unlikely that the fencing would be able to build up enough sand to fully slow the effects of waves if a big storm occurred.

4.4.3 Cisco Beach

Figure 22 shows an example of the erosion occurring on Cisco Beach.

Figure 22. An example of the erosion on Cisco Beach. The photo was captured at low tide.
Photograph by Ryan Waters

As a result, the following recommendations were made:

1. Vegetation
    a. Vegetation would help to slow the effects of erosion from smaller waves. This would help protect the shore from the erosion that is currently happening. The vegetation would help to stabilize the slope and make it less vulnerable to erosion. The smaller waves could also bring sand that the beach vegetation could catch, which would further help with accretion of sand. The slope is steeper in some places so vegetation would have to be planted in front of the slope in those areas, which would still help to limit erosion.
2. Fencing
    a. Fencing helps to catch sand blown by the wind and builds dunes around the areas. Sand Fencing would be effective on Cisco Beach as the area is not regularly reached by high tide or minor storms (Massachusetts Office of Coastal Zone Management, 2018). Sand Fencing would help to capture sand moved by the wind. This would help to build up the dunes which in turn would help protect the shore from waves caused by storms.
3. Monitoring
    a. While monitoring would allow for the bank to erode further, there are almost no houses that would be in immediate danger of being destroyed due to erosion. This means that it would be at least a few years before any of the houses would need to be relocated. In the future if the problem continues to persist the measures that the team listed above could be put into place.

4.4.4 Codfish Park

Figure 21 shows an example of the erosion occurring at Codfish Park.

Figure 21. An example of the erosion on Codfish Park. The photo was captured at high tide.
Photograph by Ryan Waters

As a result, the following recommendations were made:

1. Retreat
    a. Moving the houses back further from the slope is the most permanent solution. Relocating the houses would ensure that the houses are not in danger of falling over the cliff. However, moving a house is an expensive process which cost one couple $1.6 million in 2019 (Brandt, 2019). This is a costly option, but it is likely the most permanent solution. Moving houses lets the slope erode in its natural manner and protects the house from possible danger of being destroyed.
2. Beach Nourishment
    a. Adding sand to the beach and the slope would help slow erosion. This would give the houses and road at the top of the slope more time before they would either have to be moved or be abandoned. This process would need to be redone around every two to ten years. It would help to bring the slope back to the state of the beach before some of the erosion occurred. This is also a relatively expensive process costing around one to four million dollars per mile of shoreline (Gopalakrishnan et al., 2018). This is cheaper than having to move all the houses, but it also is not a long-term solution, needing to be redone every couple of years.

4.4.5 Timeline of Recommendations

Sand Fencing

According to the Massachusetts StormSmart page it can take as little as 2 to 3 months to complete a sand fencing project provided that only a Massachusetts Wetlands Protection Act permit is needed (StormSmart Properties | Mass.Gov, n.d.). It can take more time, but the overall process does not tend to be particularly time consuming. Sand fences can be useful, if they are maintained, for long periods of time. The maintenance for a sand fence is ensuring that the fence has not been covered in sand; and if needed, putting the sand fence on top of any newly collected sand.

Beach Vegetation

As seen for sand fencing projects it can take as little as 2 to 3 months to complete a beach vegetation project if it only requires a Massachusetts Wetlands Protection Act permit. However, vegetation can take around a year to become fully established in the ground. The length that beach vegetation is useful for varies greatly as it is all dependent on how long the vegetation is there (StormSmart Properties | Mass.Gov, n.d.). If the vegetation does not die or get destroyed by a storm it can be effective for almost an indefinite amount of time. Vegetation on banks is, in some cases, in danger of being washed away by strong waves from storms. Vegetation can sometimes actually cause more erosion if waves are big enough. The waves can pull the plants and break down the dune more easily (Feagin et al., 2023). In most cases though vegetation is helpful at building dunes and strengthening the dunes there (StormSmart Properties | Mass.Gov, n.d.).

Monitoring

The process of monitoring erosion is useful to better understand how each of the beaches is affected by erosion. Monitoring the beaches will require the beaches to be imaged regularly to assess the amount of erosion occurring. This can be achieved through GIS mapping systems, such as MORIS, or through physical markers placed at specific sites. GIS maps can provide better information for larger areas of land but can be infrequent in updates and lack detail. While changes in erosion are easily visible in the GIS system the measuring tool can be difficult to use with a great degree of precision. Meanwhile, physical markers allow for more frequent measurements of smaller areas but are subject to damage from weather (*Coastal Monitoring Project | Nantucket, MA - Official Website*, 2023). Monitoring is a good option when it is hard to implement the other methods and there are no houses and buildings in immediate danger.

Retreat

Retreating is a difficult process as it requires moving buildings and drastically altering areas near beaches. Determination of whether a building needs to be moved or not is dependent on the rate of erosion and how close the structure is to the cliff face. Moving houses or other structures is not a fast or inexpensive process. Moving a house can sometimes take years of planning and millions of dollars depending on how difficult the move is and how big the house is (Guzzetta, 2019). Retreat may be the only option for areas that face high amounts of erosion. It also can be made easier if the plot of land the house is on is big enough to allow the house to be moved only a small distance away. If the house must be moved to an entirely new plot of land that requires more planning and will likely cost more money. Additionally, it is possible that no suitable plot will be available.

Beach Nourishment

Beach Nourishment is effective for approximately 2 to 10 years. The process for getting approval for beach nourishment can be long and difficult, requiring approval from numerous agencies. Nantucket's government would need to obtain approval from the federal government to receive funding and help from the U.S. Army Corps of Engineers for the installation. The government requires that towns are willing to pay for part of the project. Not all projects end up getting approved after reviews by federal agencies, state agencies, and the Army Corp of Engineers (U.S. Army Corps of Engineers, 2007). The process of actual beach nourishment takes anywhere from a few weeks to a few months depending on the size of the project and how easily sand can be brought to the beach (*Deerfield Beach, FL - Official Website*, 2023; *Beaches in Panama City Beach, Florida*, 2022). The cost of beach nourishment is around one to four million dollars per mile of shoreline (Gopalakrishnan et al., 2018).

Regrading

Regrading a beach's slope is an effective method of making a beach more stable for the short term. When the angle of the beach slope becomes too great it poses a risk of possibly collapsing, which can be dangerous. Changing the grade of the slope can also make it easier to plant vegetation which can help to strengthen the slope (*TRPA BMP Handbook*, 2014). The timeline for a regrading project like this can vary anywhere from a few days to a month. The New

Hampshire Department of Natural and Cultural Resources states that the regrading of Hampton Beach required three to four days to complete (*Hampton Beach State Park Beach Grading Begins May 7*, 2020). The slope should have vegetation and possibly other measures on the slope so that it is effective. Regrading can last for as long as the bank is not eroded away.

5.0 Conclusion & Further Recommendations

The goal of this project was to evaluate the use of various photo capturing technologies to document coastal land, analyze coastal erosion, and develop erosion mitigation proposals for selected public locations to add to Nantucket's Coastal Resilience Plan. After documenting coastal erosion at the four public locations on Nantucket, the application of handheld photography, drone photography, and photogrammetry was analyzed. In addition, MORIS and FEMA were used to find the erosion rates and satellite imagery of the coastal regions discussed. Finally, we used all the information gathered to create coastal erosion mitigation proposals for the selected locations.

The team recommends that handheld photography, drone photography, and photogrammetry be completed at each of the four locations every year, at a minimum. If possible, each image capturing method should be used at each location every year to allow for a more complete timeline of the erosion. Additionally, photos and scans should be completed at the same tides as their current counterparts to allow for easier and more accurate comparisons to be made. As a result, both weather conditions and the current high and low tide times should be taken into consideration for determining when to complete both drone photography and photogrammetry. Drone photography and photogrammetry should also be completed at the Madaket Beach Parking Lot, Cisco Beach, and Codfish Park before additional scans of Dionis Beach are created. This would allow locations that could not be surveyed due to time constraints to receive updated points of comparison for future photographs and scans. As new methods of photo capturing become available, we suggest utilizing them to create a more diverse range of data to use for future studies.

After the scans for this project were completed, it was found that photogrammetry point clouds do not store distance measurements. Following this, the team recommends that distance markers are placed in the area prior to capturing the drone photography so that proper distance and scale can be determined for the point cloud. Alternatively, ensuring that the point cloud areas contain visually distinct sections, that can be measured from satellite imagery, will also work for determining point cloud scale.

The team recommends that all four studied locations receive some form of coastal erosion mitigation, with priority going to Codfish Park and Madaket Beach. Codfish Park, despite its low erosion rates, poses a considerable threat to property and public safety. The up to 70-foot drop from the properties along Baxter Road to the beach below is extremely dangerous (Nathanson, 2017). The houses along the bluff are susceptible to falling off the cliff face, leading to pollution of the beach and ocean below, a costly cleanup, and creating unnecessary danger for the property owners and public. To limit damage to the bluff, preserve people's homes, protect the local wildlife, and to protect the population of Nantucket, we recommend that the government prioritizes a managed retreat for the properties along Baxter Road, and works to rebuild the bluff. To do this, we recommend limiting public access to the beach, and utilizing beach nourishment. Once the bluff stabilizes, plant vegetation and build fencing to strengthen the bluff and aid the accretion of sand.

Madaket Beach has the highest erosion rate of any of the locations we looked at, with an erosion rate of nine feet per year (MORIS). This erosion rate is unsustainable and requires immediate attention. Creating an environment that promotes accretion is necessary for the beach to thrive. The parking lot is unfortunately in a dire state. It has eroded away, leading to a small, all but unusable lot, an unnatural drop of a few feet onto the beach from the lot, and a section of the beach littered with asphalt. We recommend that the parking lot be monitored, as there unfortunately is not much that can be done about it. The focus for Madaket beach should be on accretion, planting vegetation further towards the ocean and building dunes. Accretion should also be the focus for Cisco Beach.

The team also recommends that new or updated coastal erosion mitigation proposals should be written whenever coastal erosion analysis has occurred for a location. This will ensure that erosion mitigation proposals are using up to date information. This also will allow for future proposals to be based off newer photo capturing technologies that arise.

The threat of coastal erosion will not be eliminated by the results of this project; it is a greater issue that cannot be solved with one study. While this project will give Nantucket a framework to use to mitigate erosion, the issue will never fully go away. It is up to the residents of Nantucket and the federal government to protect this island community and the amazing things it holds.

6.0 Summary

The project evaluated three photo capturing technologies used to document coastal land, evaluate the changes in coastal erosion, and coastal erosion rates. The resulting data lead to development of coastal erosion mitigation proposals for specific public locations to add to Nantucket’s Coastal Resilience Plan. To accomplish these tasks, the team used handheld photography, drone photography, and photogrammetry to document the different public locations on Nantucket that have high erosion rates. This information was used to identify changes in erosion rates throughout the island, compare the different methods of photo capturing technologies, and create proposals for erosion mitigation at Dionis Beach, Madaket Beach Parking Lot, Cisco Beach, and Codfish Park.

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Appendix A: Interview Guide

The interview guides provided a basic framework for the team to conduct interviews. Using the guide helps the team to address and record topics that are important for each interview.

The guide also allows the team to have consistent wording for questions across interviews.

Expert Interview Guide:
The purpose of this interview guide was to obtain more specific information about erosion structures and what makes them effective. This helped us develop our rating scale and create our final proposal on future mitigation methods.

“What coastal erosion mitigation methods have you found to be the most effective?”

“What are factors that we should consider when trying to rank the overall efficacy of a style of erosion structure?”

“Which of those factors are the most important to consider?”

“What coastal erosion mitigation methods do you have the most experience with?”

“Do you have any experience with coastal erosion on an island? If so, did you mitigate it?”

“How do you tell when an erosion structure is functioning properly?”

“Nantucket currently has a ban on hard erosion mitigation structures, do you believe that hard structures should be allowed?”

“What soft erosion mitigation structures do you believe are the most effective? Which are most effective/applicable on islands?”

“How do you tell when an erosion structure should be repaired or replaced?”

Appendix B: Informed Consent Form

The informed consent forms are to be given to interviewees to assure that they are aware of how we will be using the information they give us and the precautions that we will take while handling their information. This form is meant to be signed by the interviewee before the interview begins to allow them to deny the use of their information in the study.

Informed Consent Agreement for Participation in a Research Study: Experts

Investigators: Michael Sterk, Peter Tzanetos, Thomas Cox, Ryan Waters

Contact Information: gr-ack23-erosion@wpi.edu

Title of Research Study: Coastal Erosion Control on Nantucket

Sponsor: The Nantucket Coastal Conservancy (NCC) and the Nantucket Civil League (NCL)

Introduction
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:
The purpose of this study is to determine which coastal erosion mitigation structures are most effective at slowing erosion damage. This will be achieved through interviews with experts on erosion and erosion control.

Procedures to be followed:
The interview will take place for 30-90 minutes at a location that is convenient for the interviewee. Two or more members of the team will conduct the interview with the expert. The interview questions will be prepared prior to the interview, and the majority of the questions will be constant for all the experts interviewed. Additionally, questions may be added that specifically relate to the interviewee's area of expertise.

Risks to study participants:
This study should have minimal to no risk to the participants. The questions in this interview will mainly focus on the facts around the efficacy of coastal erosion mitigation structures and will not go into detail on personal experiences with erosion.

Benefits to research participants and others:
There will be no direct benefits to the expert for taking part in the interview. The main benefits from the study will be to pool the existing knowledge on coastal erosion mitigation structures and to use this information to determine which structures will be an option for Nantucket to utilize going forward.

Record keeping and confidentiality:
Records of your participation in this study will be held confidential as far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identifies you by name. Any publication or presentation of the data will not identify you. Interviews will be recorded on a locked cell phone and will be deleted after being transcribed onto a digital document. This document will only be shared between members of the group and will only be accessible to these members.

Compensation or treatment in the event of injury:
Given that this study will be conducted as direct interviews with experts, it is very unlikely that any form of injury will occur, and therefore no compensation will be provided. If at any point the interviewee is uncomfortable with the questions being asked, they can decide to drop out of the interview and all of their responses will be destroyed. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:
Research Team Contact: gr-ack23-erosion@wpi.edu
IRB Manager: Ruth McKeogh, Tel. 508 831-6699, Email: irb@wpi.edu
Human Protection Administrator: Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

___________________________ Date: ___________________

Study Participant Signature

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Study Participant Name (Please print)

____________________________________ Date: ___________________

Signature of Person who explained this study

Appendix C: Photogrammetry Point Cloud Files and Instructions

This appendix contains the link to a YouTube video describing how to view the point cloud files withing the software CloudCompare. This appendix also contains the links to download CloudCompare as well as the point cloud files. Finally, there are three links to YouTube videos showcasing the 3D view of the point clouds.

Instructions for viewing point cloud (.laz) files in CloudCompare:
https://www.youtube.com/watch?v=xdwm5KHbAWI

CloudCompare (point cloud viewing) software website:
https://cloudcompare.org/

Jetties Beach point cloud courtesy of Jacob Tinkhauser (.laz) file download (935MB):
https://drone.farfetchednantucket.com/images/Jetties-Beach-11-13-2023-georeferenced_model.laz

Dionis Beach point cloud courtesy of Jacob Tinkhauser (.laz) file download (621MB):
https://drone.farfetchednantucket.com/images/Dionis-12-2-2023-georeferenced_model.laz

Sconset Bluff point cloud courtesy of Jacob Tinkhauser (.laz) file download (302MB):
https://drone.farfetchednantucket.com/images/Baxter-6-11-2023.laz

Jetties Beach point cloud showcase video:
https://www.youtube.com/watch?v=N2F21Y7jc1I

Dionis Beach point cloud showcase video:
https://www.youtube.com/watch?v=OTon6TwTWhs

Sconset Bluff point cloud showcase video:
https://www.youtube.com/watch?v=_e64FXvX_C0

Appendix D: Handheld and Drone Photos

This appendix contains the link to the Google Drive folder with a collection of the handheld photographs, taken on a Lumix G7, and drone photos, taken on a DJI Phantom 4 Pro, taken during this project.

Link to the Google Drive folder containing the photos:
https://drive.google.com/drive/folders/1GgdjYSg_OA4rwNAER9IcGOJrzVG0rVsT?usp=sharing