Beach Accessibility: Passageway Design for Massachusetts Beaches

Nadiya Chalak, Caitlin Coumounduros, Madison Garrity, and Colette Webster

WORCESTER POLYTECHNIC INSTITUTE

Advisor:

Professor Suzanne LePage

A Major Qualifying Project Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements of the Degree of Bachelor of Science of Civil and Environmental Engineering.

Abstract

The team worked with the Duxbury beach reservation and Newburyport beach representatives to bring increased accessibility to shoreline passageways while also being environmentally conscious and sustainable. The project identified a passageway for each location that would adhere to the unique constraints of each beach. For Duxbury beach, an elevated wood ramp was selected as the design to scale the high dunes and promote less disruptive movement. A rollout polyester mat was recommended for the Newburyport design to provide support to the underdeveloped pathway. The design selection process conducted can be used for future projects and includes further information regarding the implementation procedures and mechanisms of each selected pathway.

Executive Summary

Accessibility is a long-standing issue in all aspects of life. Developing adequate infrastructure that allows people to experience the world is crucial to instilling fairness, freedom, and independence for all individuals and communities. Many regulations and requirements are required for development projects to keep programs responsible and aware of accessible implications. These regulations allow easy transport and navigation for individuals including wheelchair users, those with disabilities, and children, among others. This has made the process of path development difficult for beaches to navigate while adhering to all regulations.

Infrastructure also impacts other species' accessibility as well as the environment. Species are displaced from their homes due to construction projects. Wildlife species are vital to the natural world and require effort to keep them protected. Implementations also affect the ecosystem as it stands, stripping away native vegetation and habitats. Erosion and storm damage also deteriorate manmade structures and human habitats. This Major Qualifying Project (MQP) worked towards solving these constraints by designing adequate passageways for two distinct beach locations - Newburyport and Duxbury.

At each site, one specific area was focused on to produce the most applicable design recommendation. Both passageway locations have had current standing issues with accessibility as they were under-developed pathways or new pathway sites. They also both contain unique challenges from the environment which has constrained the designs' abilities to be properly implemented.

The Newburyport shoreline is shrinking due to rising sea levels and erosion, bringing water closer to residential homes. Sand dune systems have been developed to defend the beach and homes from tides. However, sand dunes create a barrier that prevents easily navigable passageways. The desired passageway location has other physical obstacles as well including concrete blocks that crowd the entrance of the path (**Figure 1**). Neighbors have also resisted the development of a larger infrastructure project near their property.

Figure 1. Location of Newburyport passageway.

As of this report, Duxbury is undergoing a large dune nourishment project that is projected to raise dune elevation to 16 feet in the area of the desired passageway. This height will

require a design that will scale the mound without disturbing the vegetation growth necessary for storm protection. This path will serve as a brand-new access point for the beach that will allow travel across the dune from the parking lot and facility building to the shoreline (**Figure 2**).

Figure 2. Location of Duxbury passageway.

The team helped Newburyport Beach and Duxbury Beach Reservation select the best passageway design for each individual area's environmental and accessible needs. The team made the process of selecting the proper pathway type easy to follow and replicate for future designs and alternate beaches. The team documented each step in deciding on the proper passageways and formatted the information in a simple yet understandable manner.

Various materials were researched to uncover their physical properties and how they would perform to the conditions at the different beach locations. The team created comparison tables to display the differences and similarities between the materials. It was found that Kebony wood and polyester were the most applicable.

The team relied heavily on the opinions of industry experts and those who were familiar with the Newburyport and Duxbury Beach Reservation areas. Preliminary designs were presented to these individuals for their insight and to understand how these designs could better fit pathway needs. The team presented their findings and conversed with these experts who helped in the overall project process. Independent research was used to further explore ADA regulations and other access design restrictions. This affects factors such as guardrails, slopes, and width.

The team decided on a roll-out Mobi-mat design as the best fit for Newburyport and an elevated Kebony wood structure for Duxbury. These designs may be expanded upon as part of a future MQP. Information is also presented throughout this report on how to best implement these designs in terms of construction, cost, and regulation compliance.

Acknowledgements

This project would not have been possible without the help of the many professionals that advised, supported, and contributed to this project. Our team would like to thank **Julia Godtfredsen** of Newburyport Massachusetts, and **Sue MacCallum** of Duxbury Massachusetts who sponsored this project and will continue on its success. Julia Godtfredsen connected us to **Darryl Forgione**, a Regional Engineer who provided us with examples of existing passageways in Massachusetts and sustainable materials to design from past successes and failures. Sue MacCallum connected us to **Bradford Bower**, Coordinator for Duxbury Beach Reservation's Coastal Ecology Projects, who provided us with multiple documents and information about the Reservation and future plans for sand dune restoration and passageways. We would also like to thank DCR's **Rachael Lee**, Site Accessibility Specialist, and **Tom McCarthy**, Director of the Universal Access program, for their detailed insights and experiences related to beach accessibility. Ultimately, special thanks to our academic advisor **Professor Suzanne LePage** who sanctioned this project and provided guidance and exceptional feedback. The Town of Newburyport, Duxbury Beach Reservation, and industry experts all inspired us to design and recommend accessible and environmentally conscious mats and passageways.

Authorship

The Major Qualifying Project (MQP) was completed by four Civil and Environmental Engineering undergraduate students at Worcester Polytechnic Institute. All team members contributed to the writing and editing of this all sections of this report, as well as research and design of our solutions.

The primary author of each section is listed as follows. Team member Nadiya Chalak wrote the Acknowledgements, and Introduction and Background chapters. Team member Catie Coumounduros wrote the Professional Licensure Statement, Results and Recommendations chapters and created the CAD concept designs of each passageway. Team member Madison Garrity wrote the Methodology chapter, Abstract, and Executive Summary. Team member Colette Webster wrote the Conclusion chapter and Capstone Design Statement.

Capstone Design Statement

Worcester Polytechnic Institute (WPI) requires all students to complete a capstone design project, which is known as the Major Qualifying Project (MQP), as one of its graduation requirements. In order to satisfy the capstone design criteria as defined by the Accreditation Board for Engineering and Technology (ABET), this project considers the following constraints: economic, environmental, social, political, ethical, health & safety, manufacturability, and sustainability. This project meets the capstone design requirement by providing beach access on Plum Island and Duxbury Beach through the design of an accessible passageway for each location. Accessibility to our team is defined as equitable to all persons regardless of disability, physical limitations, or mobility.

On Plum Island, located in Newburyport, MA, the passageway will give beachgoers a clear path where it is safe to cross without disrupting the surrounding environment. This passageway will travel from Reservation Terrace to the beach. On Duxbury Beach Reservation, in Duxbury, MA, the passageway will travel over the replenished sand dunes, connecting the parking lot to the beach. The path will avoid piping plover nesting and preserve the sand dune habitats.

Our project evaluated the design criteria and associated environmental implications to determine the best methods for accessible beach passageway construction that will be most beneficial to both Plum Island and Duxbury Beach Reservation. The following constraints were addressed during the progression of our design:

Economic

Financial considerations are important in determining the feasibility of our design. A cost estimate was prepared for each of the two beach locations, and potential funding sources were identified. While there was no defined budget for either location, material and implementation costs were considered to ensure a balance between quality and affordability.

Environmental

This project addressed environmental constraints by constructing around vulnerable ecosystems, including sand dunes, Piping Plover habitats, and beach vegetation. The design recommendations work to maintain the natural movement of sand dunes, which is essential for coastal infrastructure.

Social

Social concerns were addressed by selecting passageway locations that were not situated too close to homes or private property. Abutters in close proximity to the beach initially expressed disapproval of a formalized passageway directly behind their property, so an alternate location was selected.

Political

Property ownership was accounted for to determine that passageways were not being designed on privately owned property. The team worked with local planning members for each beach to ensure that the selected sites were publicly accessible. The team also communicated with conservation managers to ensure that protected bird species would not be disturbed by the implementation of our design.

Ethical

This project abided by the American Society of Civil Engineers (ASCE) Code of Ethics. Fundamental ethical principles were followed throughout the design process, resulting in the creation of safe, resilient, and sustainable infrastructure. The team considered the most significant needs of both project sites, focusing on improved beach access and dune preservation for protection of coastal habitats and properties.

Health and Safety

The safety of all beachgoers was a major consideration of this project. The team researched and applied ADA compliant guidelines to ensure that each path is safe for all-person usage. Furthermore, the health of the environment was considered by selecting materials that will not harm the surrounding habitats.

Manufacturability

The project accounted for constructability of the passageways by assessing the needs of each location. This allowed the team to select materials that were available and feasible for implementation to current conditions on each beach.

Sustainability

Different materials were considered for each location dependent on the needs of each beach. Durable materials were chosen to resist erosion, rising tides, and storms. Removable aspects were considered to maintain the passageway during winter months and harsh weather. Potential impact of materials on the surrounding ecosystem was also considered to ensure that no harm would be inflicted on the natural environment long-term.

Professional Licensure Statement

The National Council of Examiners for Engineering and Surveying (NCEES) oversees the Professional Engineering (PE) licensure to ensure that engineers in the United States are all held to the same high standard of engineering practice. Any candidate wanting to obtain their PE status must first receive a degree from an ABET-accredited college or university. The next step to becoming a PE is by studying and passing the Fundamentals of Engineering (FE) exam to become an Engineering in Training (EIT). Some employers prefer new employees to take the FE exam while they are still in their senior year of college, while others will help new employees study and work towards passing during their first year of employment. After passing the FE exam, a candidate must work in the Civil Engineering (CE) industry for a minimum of four years under a licensed PE to understand engineering concepts and principles, and gain experience using them in everyday work. After four years in industry, a candidate must pass a second test, the Principle and Practice of Engineering (PE) exam, which is administered by a State board. If the candidate passes the PE test and has fulfilled all other requirements listed by the state they are applying to, the candidate obtains their PE license in that state. A PE license is only valid in the state that the candidate applied for, although it is simple to transfer your licensure to another state under NCEES approval.

Obtaining a PE license is a very valuable asset in the CE field. Engineering plans can only be approved and stamped by a PE, making them a necessary component to any CE firm. Often at CE firms, there is more opportunity to move up in positions and salary only with the PE licensure. It is difficult to move out of an entry level CE position without the ability to stamp and approve engineering plans or documents, making the PE a valuable license to obtain. In the next steps of this MQP, a PE would need to be consulted in the structural design and construction of any elevated structure.

Beyond promotional and career incentives, PEs are valuable, contributing members of society. PEs guarantee the safety of public and private buildings, roadways, and infrastructure for the entire human population. Without them, there would not be nearly as many amazing building designs, or even just simple highways to get from point A to point B. Safety is of the utmost concern for a PE, ensuring that every project they approve will be safe for the public and its usage.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

Massachusetts' beautiful coastlines are among the state's most popular tourist destinations, but their popularity is not enough to save their place on this planet. Coastal zones are particularly vulnerable to various kinds of pollution, human alteration, erosion, and climate change impacts, all of which are threats to beach environments and beach access. The long-term existence of beaches like Plum Island and Duxbury Beach Reservation are not guaranteed as they are eroding at alarming rates (**Figure 1**).

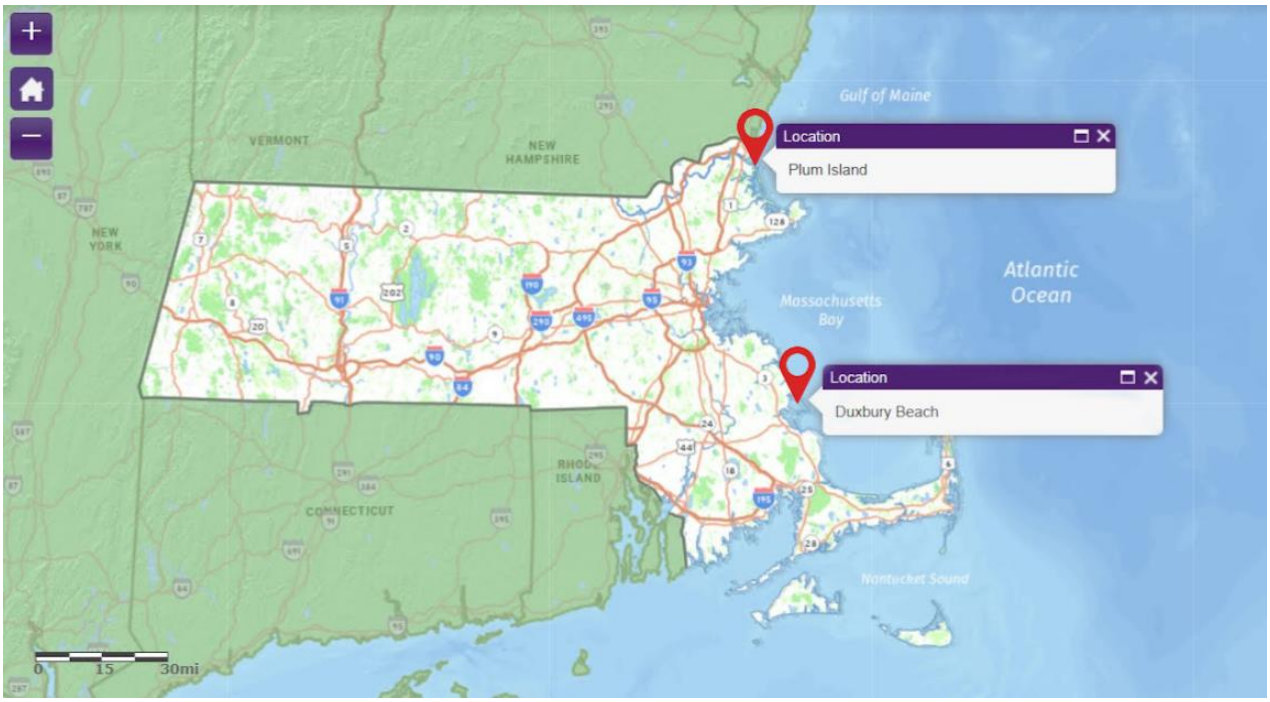


Figure 1. Massachusetts map showing Plum Island in Newburyport and Duxbury Beach Reservation in Duxbury.

Shrinking beaches affect the livelihoods of local communities today, particularly in Massachusetts as not everyone has equitable access (Van Buskirk, 2021). In a state where only 12% of beaches are open to all members of the public, Massachusetts loses approximately 65 acres of coastal upland per year due to passive shoreline retreat as a result of sea level rise. In addition, approximately 72% of the Massachusetts shore has been exhibiting a long-term erosional trend since 1950 (Oktay, 2013). Rising sea levels and increased storm activity cause erosion and flooding of coastal areas, which wreaks havoc on marine ecosystems, species, beachgoers, local economies, homes, and businesses. Locals are facing the difficult decision of whether to rebuild or relocate. Seawalls, beach nourishment, and planting beach-friendly native vegetation are all solutions that Plum Island in Newburyport and Duxbury Beach Reservation have done to limit sea level impacts. Some areas of Plum Island have seen 50 to 100 feet of erosion and within 50 years, some parts will be untenable as a result of daily high tide flooding

(Gurley, 2015). Flooding and erosion also affect the ability of a beach to maintain ADA requirements and standards.

Passageways – like boardwalks and walkways – are structures that provide beach access over sand dunes. If properly designed, passageways minimize impacts of erosion, storm damage, waves, wind, and flooding and instead maintain pedestrian access in one location, discourage widespread traffic of vegetation, allow for the natural movement of sand and other sediment, and stabilize dunes to protect coastal properties (MA Office of Coastal Zone Management, 2022). These passageways supply people with clear spaces to maneuver to the beach comfortably without immense destruction to dune structures and animal habitat disturbance.

Sand dunes protect beaches and communities from erosion, acting as a natural barrier absorbing and dissipating wave energy before it reaches the beach and nearby communities. The height and vegetation of the dunes slow wind and water, reducing the velocity of storm surges and floods. Issues arise when these fragile mounds become damaged and torn from humans, its leading destroyers. Limiting foot traffic near and around these areas is the most effective way to protect them. One measure that steers foot traffic away from dunes, protects marine habitats, and allows all visitors a safe route is by constructing clear, and defined passageways. Both Plum Island and Duxbury Beach Reservation recognized a need for dune stabilization to prevent further erosion but also for creating passageways to allow beachgoers to safely access their beaches. This project aims to solve exactly that: recommending accessible passageways for all beachgoers that consider the environmental constraints and surrounding ecosystems of sand dune and piping plover habitats, for various Massachusetts beaches.

Chapter 2

Background

This chapter provides the context behind Plum Island and Duxbury Beach Reservation, the conservation of sand dunes and Piping Plovers, beach accessibility, and relevant construction designs, that are referenced and built upon throughout this MQP.

2.1 Newburyport Beach

Plum Island, a Barrier Beach in Newburyport, Massachusetts is a treasured destination for over 250,000 annual visitors who enjoy relaxing on the narrow, low-lying strip of beach and coastal dunes. While this public beach is frequently enjoyed by visitors, the upscale private properties on the island are becoming increasingly occupied by year-round residents (*Plum Island Beach*, 2022). With the addition of residents in the area, environmental issues like erosion, climate change, and interference with wildlife populations and habitats have grown worse (**Figure 2**).

Figure 2. Sand dune erosion on Plum Island.

Located at the mouth of the Merrimack River, Plum Island Beach has faced erosion problems over the past several years; the dune system has experienced over 400 feet of erosion (GZA GeoEnvironmental, Inc., 2021). An ongoing project is underway to combat this erosion by placing dredged sand material as beach nourishment to build the shrinking shoreline, replenish dunes, and protect the coastal properties and threatened bird habitats of Piping Plovers and Least Terns. Throughout this project, the U.S. Army Corps of Engineers will dredge nearly 300,000 cubic yards of sand from the Merrimack River to place on the eroded dune system, which will be completed as by March 31, 2023.

2.1.1 Accessibility Issues

Due to the erosion and changing landscape of the beach, Plum Island has faced issues in areas of accessibility with restricted passageways, conservation, and limited wheelchair access. Some areas of the island have boulders to protect residential properties to combat the erosion problem. These boulders, however, have ultimately disrupted the flow of sand which has led to further erosion problems. Sand restoration for sand dunes is needed to counter the shrinking shoreline. Sand dunes also act as protection to residential homes and are a habitat for various wildlife species such as Piping Plovers. One of the current passageways is not ADA accessible due to the cinder block obstruction located at the beginning of the path to keep sand from pouring onto the street. Another outstanding issue is the self-made passageways that have not been maintained. For example, at the main entrance of the beach, there is broken fencing that was once used along one path. Other passageways close seasonally to protect Piping Plover nesting and population. Maintaining accessibility standards is critical to facilitate the movement of all beach visitors.

2.1.2 Plum Island Stakeholders and Liaisons

Plum Island is largely managed by the United States Fish and Wildlife Service in the Parker River National Wildlife Refuge location, while the Massachusetts Audubon Society operates the Joppa Flats Education Center and Wildlife Sanctuary. Residents who live on the beach also own their portion of the beach to the tidal line. The remaining portions are owned by the town of Newburyport. Julia Godtfredsen, the Newburyport Conservation Administrator, and Darryl Forgione, Regional Director, have been working with DCR to promote the existence and future of these passageway recommendations.

2.2 Duxbury Beach Reservation

Duxbury Beach is an accessible, family-friendly, 7.5-mile-long barrier beach located in Duxbury, MA. Similarly, to Plum Island, Duxbury is seeing a shift from summer residents to year-round residents (NSRWA, 2022). Duxbury Beach also faces issues from erosion and the decline of wildlife habitats and populations of Piping Plovers. Like other barrier beaches, the sand at Duxbury Beach moves and changes over time. Due to the sea walls of beaches to the north, Duxbury Beach is not receiving the natural nourishment of sand needed to maintain the dunes. An ongoing project at Duxbury Beach Reservation aims to create a natural approach to alleviate erosion by placing cobbles around Powder Point Bridge. Sand and cobbles are used to build up the dunes, with the goal of preserving the beach, including its coastal bird habitats and vegetation (Stone Living Lab, 2022).

2.2.1 Accessibility Issues

Duxbury Beach relies heavily on generous donations from the public to keep the Reservation adequately funded and operational. The 7.5-mile-long barrier beach has caused a natural split between areas available for residential access and others solely devoted to the

public. There are crossovers available, where vehicles drive up to the beach, but this area is closed during Piping Plover hatching and return seasons in the summer months (**Figure 3**).

Figure 3. Vehicle crossovers at Duxbury Beach Reservation.

Crossovers allow easy accessibility for vehicles to drive directly onto the beach. However, there are no mats or passageways around for those without cars or who require wheelchair access to easily navigate through uneven terrains of the beach. Other wooden passageways available are ADA accessible with removable structural designs in case of storms to prevent damage and weathering.

2.2.2 Duxbury Beach Reservation Stakeholders and Liaisons

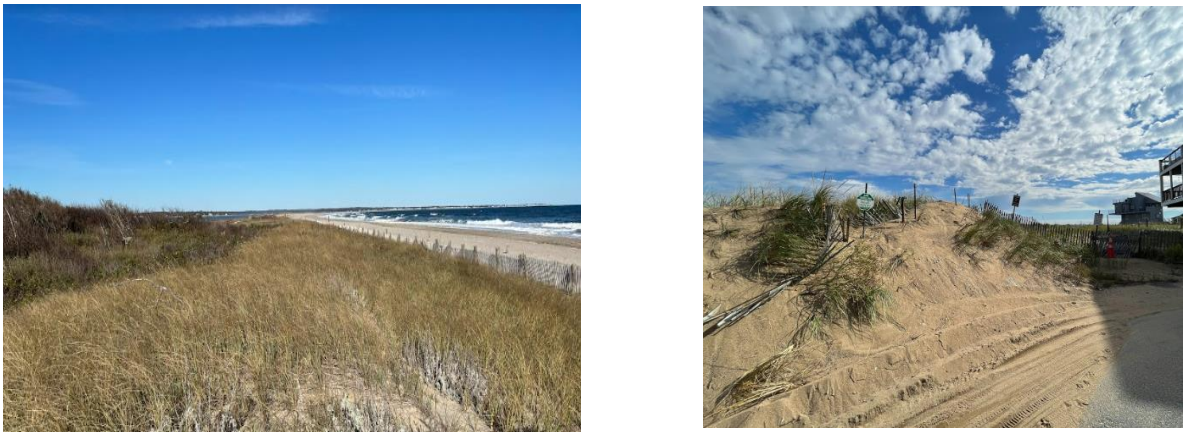
Duxbury Beach is owned by Duxbury Beach Reservation Inc., a Massachusetts charitable corporation with a mission to preserve and safeguard the adjacent bays and mainland and protect wildlife and vegetation while welcoming the public to enjoy (Duxbury Beach Reservation Inc., 2019). The Reservation leases a portion of the beach to the town of Duxbury for both resident and public use. Duxbury beach requires parking permits for crossover utilization, in addition to the residents-only parking lot. An important member of the beach is Sue MacCallum, an Outreach Coordinator who works with both the Town of Duxbury and Duxbury Beach Reservation. Bradford Bower, Program Coordinator of the Coastal Ecology Program of Duxbury Beach Reservation, is another notable asset to the beach who has assisted MacCallum and Duxbury's plans of creating an accessible passageway and its design.

2.3 Conservation of Sand Dunes

Sand dunes are a fundamental habitat for beach ecosystems, and they factor into infrastructure development such as passageways. Before developing a design, one must understand the role sand dunes provide. Sand dunes must be preserved for wildlife inhabitants and beachgoers.

2.3.1 Sand Dunes

A sand dune is the accumulation of sand formed by wind, waves and eroding sandstone. It is a structure that is constantly changing and growing due to natural patterns of the wind and the coastal tide (England, 2022). Coastal sand dunes are a highly dynamic, natural system composed of the shoreface (*the open, sandy area between the dune and the high tide line*), and beach itself. Sand dunes form when sand piles against an object like seaweed, rock, or driftwood. Over time, the sand grows large enough for plants to flourish (**Figure 4a & 4b**).



(a) (b)

Figure 4. Sand dunes at Duxbury Beach Reservation (a) and Plum Island (b).

Since sand dunes are regularly exposed to harsh weather elements, they are considered a "fragile" ecosystem. Sand dunes battle constant erosion to protect the coastline, inland beach, and residential homes, as well as provide habitats for species such as the Piping Plover. Normally, during events of high tidal waves or destructive storms, sand dunes take wind and water patterns to disperse energy across the coastline and create a protective front to communities and property that lie directly behind them (Heurtefeux, et. al., 2021). A healthy dune means minimal erosion and displacement. It can protect the beach at its best ability and facilitate the movement of sand naturally through itself and back on to the beach without major coastal erosion; the rising tide will continuously take sand from the beach deeper offshore under the sea level (Jesse, 2008). Sand dunes are undeniably important as they provide a variety of these ecosystem services and protective functions.

The existence of a sand dune is at risk from the threats of off-road vehicles, human foot traffic, invasive beach grass, construction of residential and business properties, recreation, erosion, and sea level rise. These threats create unadaptable dunes that are no longer able to serve as a sufficient buffer against erosion (*Importance*, 2022). The lack of fresh sand serves as a primary breeding ground for invasive plant species. Deflation of the dunes is also a risk when wind remobilizes the sand and blows it out of the dune, displacing much of the volume of the mounds. One way to protect sand dunes from these threats is through natural creation and replication.

2.3.2 Creating/Replicating Natural Sand Dunes

The process of creating and replicating natural sand dunes is known as dune restoration. This process typically involves site assessment, sand source identification, sand placement, vegetation planting, monitoring, and maintenance.

The first step in the restoration process is to assess the site by determining its suitability. Site assessments check sand availability, slope of the beach, and presence of existing vegetation. A sand source from nearby beaches or dredging operations is then used if the material has similar grain size and composition. Sand is transported from a nearby beach to the assessed site and spread to mimic the natural shape of the dune. Native vegetation such as Marram Grass (*genus Ammophila*) and American Beach Grass (*Ammophila breviligulata*) are used to stabilize the dune. Plant roots hold sediment in place, which stabilizes the areas where they are planted. Plants absorb water which slows the speed of overland runoff and erosion. As a result, the dune grows stronger and more resistant to environmental conditions like erosion. Therefore, dune maintenance must involve the removal of invasive species of grass such as Common Reed (*Phragmites australis subsp. australis*), replanting native vegetation, and adding more sand.

In late 2022, Newburyport began a $9 million project with 220,000 to 300,000 cubic yards of sand to be dredged which adds more than 400 feet of beachfront to rebuild a part of the beach. Over the last couple of years, erosion has caused the coastline to inch closer to homes. Roughly two years ago, a road in front of houses was washed away. In the winter of 2021, one home was condemned due to flooding. Since then, the city and state added sandbags and a stone wall along the edge of the street that has temporarily stabilized the situation (Rogers, 2022).

In 2018, Duxbury Beach Reservation spent approximately $685,000 restoring dunes, rebuilding roads, mending fencing, and planting vegetation. To increase the resilience of the beach, 76,633 tons of sand were installed and graded to raise 3,500 linear feet of the dune to 17 feet in elevation and extend the top of the dune to a maximum width of 45 feet. Approximately 3,600 feet of sand fencing was replaced to protect the dune from foot and vehicle traffic and trap sand to help build the dunes. Two vehicle crossovers were raised and realigned, and 80,000 culms of American beach grass and 100 woody shrubs were planted. (Duxbury Beach Reservation Inc., 2019).

The success of sand dune restoration depends on several factors such as the amount of sand, type of vegetation, and site conditions. Impacts on the surrounding ecosystem, permits, and financing, impact project success. These temporary restoration solutions require several years for official dune stabilization. However, crustaceans, native plants, and migratory bird species like the Piping Plover, are grateful, and locals know their homes and property are protected.

2.3.3 Piping Plover Importance and Role in the Ecosystem

Piping Plovers are an indicator species that allow scientists to understand the condition of the ecosystem they live in and for the health of beaches and dunes as they require a specific habitat to thrive (Vinelli, 2000). Their role and ecosystem importance is attributable to their breeding pairs and beach cleaning they provide. Plovers' contribution to the environment stems from their control over their predators such as Gulls and foxes, as well as prey populations of insects, beetles, and small crustaceans. The abundance of breeding pairs in an ecosystem reflects the availability of beach nesting habitats and success of management efforts to protect them from human disturbance, storm tides, and predators (**Figure 5a & 5b**).

(a)

(b)

Figure 5. Examples of Piping Plover nests. (a) shows a nest in a shallow scrape of sand with vegetation (Bellman, 2022) while (b) shows a nest in a shallow scrape of sand surrounded by rocks, shells, and vegetation (Seccombe, 2008).

If Piping Plovers went extinct, their prey population would increase, while their predators would decline, as one of their main food sources would become unavailable. If one species in the food web ceases to exist, one or more members in the chain will too. The circle of life in the sand dune ecosystem would be imbalanced. Ecological balance leads to the continued existence of organisms and ensures no species is exploited or overused.

Wildlife management manipulates components of endangered species' habitats to ensure survival like altering vegetation in an area to provide proper food and cover. Plovers are particularly vulnerable to off-road vehicles, encroaching human development/disturbance, and erosion. Off-road vehicles uproot Plover habitats by directly killing adult birds, eggs, and destroying nests. Human development and activities, along with urbanization contribute to the decline of their population. High human traffic levels increase the likelihood that Plover eggs and foraging will be disturbed. Plovers interrupted by humans stop foraging, move away from the area, then wait until the disturbance no longer exists (Webber, Heath, & Fischer, 2013). In doing so, they spend too long avoiding the disturbance and not enough time hunting for food for survival. Plastic pollution and erosion are an exacerbated result of human development. Birds are loyal to their beaches, even if the stress would kill them. One solution to mitigate human disturbance is by creating accessible and sustainable beach passageways away from sand dunes and Piping Plover ecosystems.

2.4 Beach Accessibility

There are state accessibility standards for beaches that have endangered wildlife populations and for visitors who need ADA accessibility. These standards apply to ramps, beach mats (Mobi-mats and wooden pathways), beach wheelchairs, and transportation systems.

2.4.1 Ramps and Wooden Passageways

Pathways and ramps are physically accessible travel accommodations that are required at public beaches. Clear, constructed, and visible passageways allow easy and inviting methods for guests. Ramps are commonly used when incorporating beach designs and are made of a variety of materials. Sustainable considerations are necessary to mitigate environmental impacts.

Vegetation often works with the beach landscape to prevent flooding and mass erosion. Absorbing qualities of the plants keep such environmental processes at a halt and slow their destructive properties. Ramps must not disrupt a sand dunes' structure including its vegetation and movement. In clearing areas to construct ramps, a significant amount of vegetation is removed and altered, which removes the positive impact native plants hold on the beach landscape (Accessible Beaches, n.d.). Certain ramp infrastructures are detrimental to sand movement by blocking sections from natural rearrangements. A permanent ramp structure is unsuitable to fit the continuous changing landscape.

Rails are also an important component to the ramp design. To remain in compliance with the National Council on Disability, rails must be equipped on both sides with an 11.5-inch space between the handrail and the attached wall (BraunAbility, 2021). The rail must also be constructed with no gaps and be a strict 34-38 inches above the ramp floor.

The initial construction ramp cost varies depending on material and size from $25,000 to $100,000 (Accessible Beaches, n.d.). However, many smaller and unfunded beaches do not have a budget for a structure of this nature. **Figure 6 s**hows a permanent wooden structure passageway at the main entrance of Duxbury Beach Reservation that is adaptable to weather conditions.

Figure 6. Accessible wooden passageway at Duxbury Beach.

Wooden passageways are made of various wood materials but are a more expensive, sustainable option that grows more durable, weather, and water-resistant over time. The rigid wood is flexible in design as wood passageways fit the shape of the environment and allow sand movement underneath. Wooden passageways should be ADA-compliant and require handrails for those who require extra mobility assistance. Some passageways are designed with removable features to consider the movement of various wildlife species and weathering. Like with any accessible passageway, a wooden passageway must be directly connected to solid unsanded areas so that wheelchair movement and access is easily navigable.

2.4.2 Mobi-mats

Beach mats are a less expensive, alternative option to permanent passageway infrastructures that provide ADA accessibility to those who require a wheelchair or other applications. Many of these mats are made of a non-slip rubber material and are more consistently priced, averaging about $10,000 for each passageway (Miller, 2022). The sand and mat combination creates a firm texture that acts well with the wheels of a wheelchair to facilitate movement (Mobility, 2022). These mats are already present at many Massachusetts beaches, including the Mobi-mat (**Figure 7**).

Figure 7. ADA accessible Mobi-mat on a beach (Lowthers, 2018).

Created by Deschamps Mats Systems Inc., Mobi-mat is the world's most earth-friendly, roll-out ADA accessible pathway, that serves as a temporary roadway and boat way mat system (Deschamps Mats Systems Inc., 2020). Mobi-mat is a stable, 100% recycled polyester rollout that is sustainably produced through recycled plastics. Mobi-mats are accessible to those who use walkers, elderly visitors, parents with strollers, and those who have visual impairments. It is water, salt-water, and mildew resistant. Sand also filters through its permeable surface and requires low maintenance of sweeping, brooming, or leaf blowing.

2.4.3 Beach Wheelchairs

To cater to those living with various disabilities, beach wheelchairs are provided at some beaches and are specifically designed to handle sandy terrain. Without these chairs, many are unable to access beaches, due to their limited availability. There is limited supply, and their availability is dependent on Massachusetts park staff to provide the chair (Beach wheelchairs,

2023). DCR and Massachusetts beaches supply these chairs to the public, however it is not always a simple process to use and obtain them. Beach wheelchairs require a generally flat and clear path for movement and often require difficult areas and directions to navigate. These issues all affect chair access.

The two types of beach wheelchairs offered − for traversing sand and floating on water − both require assistance and supervision. Many Massachusetts locations have one type or the other; some do not provide wheelchairs at all (Beach wheelchairs, 2023). Issues in design are present even with many chairs on the market today. Functionality issues arise when maneuvering through the sand and rough terrain. Some designs are better equipped than others, but it costs to do so independently.

2.4.4 Transportation System

Beach parking and transportation are vital to visitors navigating the coast. Massachusetts has many private access beaches that require strict parking permits for those not living within walking distance. Many beaches do not have enough parking passes and parking lot spaces for desired populations to spend a day at the beach (Burrell, 2022a). The ability to secure a parking spot near the beach is important to distant travelers, but this is difficult for lower income families that cannot afford to live in the area or purchase passes. Constructing more parking areas and constituting a bus or alternative organized beach transportation system remains the solution.

2.5 Beach Construction

To maintain conservation, environmental sustainability, and accessibility standards, there are procedures and tips to be followed. During the construction and maintenance phases of a project, natural ecosystems must be protected that surround the construction area, like sand dunes and the species that habitat within them (MA DCR, 2015).

2.5.1 Design Tips for Beach Construction

The Massachusetts Office of Coastal Zone Management (CZM) has standards for the basics of building beach access structures to limit and prevent potential harm to natural surroundings during the design and construction process (MA Office of Coastal Zone Management, 2021). Structures should be no wider than 4’ (48”) and no longer than necessary to access the beach (England, 2021). Larger structures limit the growth of beach grass, which is vital to maintaining the proper functions of a natural dune system (England, 2021). Elevating structures at least 2’ (24”) above grade of the shore allows sand, grass, and sediments to resume natural movement patterns underneath the structure, while also protecting them from being trampled by human foot traffic (MA Office of Coastal Zone Management, 2022). Structures should not block beach ecosystems from sunlight. Spacing planks 1” apart to allow for sunlight to pass through while not posing a danger to users, is suggested.

The length and time of construction harms vulnerable ecosystems. Therefore, construction occurs when beachgoers are infrequent during the fall, early spring months, or when peak winter storm season has passed. Winter construction exposes vulnerable areas, including bird nests, dunes, and coastal properties, to intense Massachusetts storms. Materials must be rot-resistant and not deteriorate from the state's changing climate. Materials should withstand snowstorms, sand erosion, and salt water.

Wind patterns play a key role in determining the direction of the access way. Sand dunes rely on natural wind tunnels to provide the wind energy required to transport and move sand, which enables the natural movement and transformation of the dune to stay strong as a barrier against erosion and flooding (England, 2021). Wave tunnels, powered by and in the same direction as the wind, are vital to replenishing the dunes with fresh sand and allowing natural movement. The access way should be angled away from the dominant wind direction in order to avoid the impact to natural wind and wave tunnels (**Figure 8**).

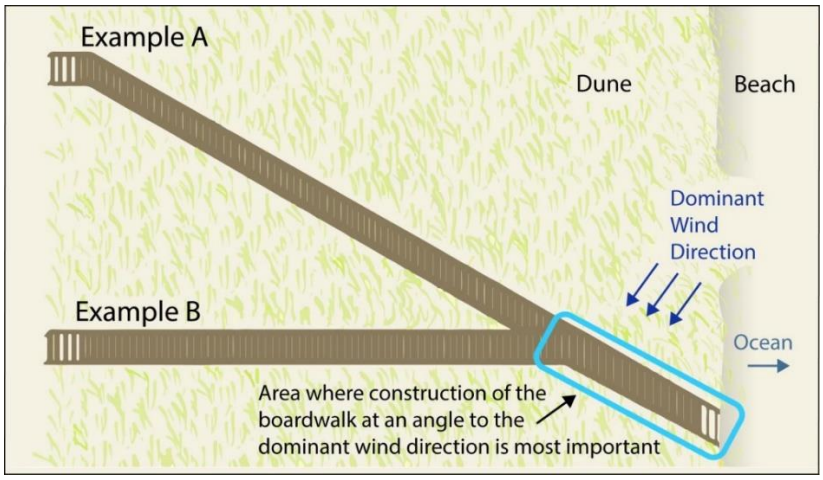


Figure 8. Boardwalks correctly constructed at an angle to dominant wind direction (MA Office of Coastal Zone Management, 2022).

2.5.2 Permitting Information

Beach construction requires a great deal of permitting before proceeding. Beaches are protected by the Massachusetts Wetland Protection Act (WPA), which protects waterfront areas from destruction or alteration in the state of Massachusetts (MA Department of Environmental Protection, 2022). The WPA allows pedestrian walkways on dunes as long as it minimizes human disturbances and promotes natural sand mobility of dunes. Due to the structure being close in proximity to nesting habitats of endangered species, any design warrants review by the Natural Heritage and Endangered Species Program (NHESP) (Division of Fisheries and Wildlife, 2022). NHESP ensures that the nesting of endangered species, including Piping Plovers, are not impacted by new construction.

Other permits that vary by location include the state's Chapter 91: Public Waterfront Act and Waterways Regulations (310 CMR 9.00), and federal Rivers and Harbors Act and Program

Regulation (MA Office of Coastal Zone Management, 2022). Other permits surrounding dune construction include the Massachusetts State Building Code, and local Conservation Commission and Massachusetts Department of Environmental Protection's (MassDEP) Wetlands and Waterways program. Permitting through various local, state, and federal agencies are required for beach construction through dunes, including ADA regulations.

2.5.3 ADA regulations

In 1990, The Americans with Disabilities Act (ADA) became a law. The ADA, a civil rights law that prohibits discrimination against individuals with disabilities in all areas of public life, including jobs, schools, transportation, and all public and private places that are open to the general public, includes regulations that require public beach accessibility to those with disabilities in wheelchairs (ADA National Network, 2023). These regulations include requirements for beach access passageways, including the width and slope of various mats and boardwalk applications. Beach facilities such as restrooms and showers, must also be accessible to individuals with disabilities. Additionally, the ADA requires that beach activities and programs, such as lifeguard services, are available to those with disabilities. Although the specific requirements may vary depending on state and local jurisdiction, the team focused purely on Massachusetts guidelines and its own implementations.

There are several American with Disabilities Act (ADA) guidelines that designs must follow to remain compliant with safety precautions. One regulation regards steepness while others dictate the procedure of construction and placement in relation to sand dunes. A slope too large is dangerous for those in wheelchairs and those with other walking disabilities (Darlington, 2016). Specific ADA requirements also cater to the population of disabled beach users. The slope of the ramp must not exceed a 1:12 ratio and must be more than 36 inches in width depending on the state regulations of the area (BraunAbility, 2021). The edges of the ramps must have established protected edges to maintain safety. The entry and exit way should be wider to allow for safe maneuverability and be designed with landings at least 60 inches in length. Rest platforms should be placed every 30 feet so there is space for breaks to avoid fatigue.

One of the greatest challenges of beach access is due to the ground surface (sand) and dune crossings that change over time. A beach access route is a continuous, unobstructed path that crosses the surface of the beach and provides pedestrians access to the water. Beach access routes may be permanent or removable, where restrictive permits are issued in coastal and shoreline areas, where seasonal tides or high flows may remove a damaged or permanent structure, or in areas where the beach erodes or builds up quickly each season and causes a permanent route to become inaccessible (Cornell University, 2020).

At least one beach access route must be provided for each one-half mile of beach shoreline administered or managed. The number of beach access points is not required to exceed the number of pedestrian access points provided to the beach. In high-density population areas, beach access routes should be provided a minimum of every one-half mile to prevent those with disabilities from traveling extensive distances to access the beach (Cornell University, 2020). Whenever possible, it is recommended to supply a beach access route that extends into the water that will allow people to remain in their mobility devices and transfer directly and easily into the water.

Chapter 3

Methodology

The goal of this project is to provide recommendations for accessible passageways for all beachgoers that consider the environmental constraints and surrounding ecosystems, including sand dunes and piping plover habitats, for various Massachusetts beaches. Newburyport Plum Island Beach and Duxbury Beach Reservation were two sites that required individual passageway examinations. Each site's developmental process began with specific documentation and information about the beaches and their accessways. Both passageway designs were then developed, analyzed, and evaluated for feasibility before creating final recommendations.

3.1 Preliminary Project Design Research

It was crucial for the team to become knowledgeable of the project's topics by becoming familiar with examples of similar past projects. Research, communication, and observations were necessary in defining the project and assessing each design's needs.

The process of the preliminary design research stood as follows:

1. Reach out to beach organizations to find a project sponsor.
2. Identify the project and accessibility need for the beach.
3. Research additional case studies and examples.
4. Conduct site visits.

3.1.1 Expert opinion and correspondence

The team first had to find a location that had an identified need for increased beach accessibility. Numerous emails were sent to Massachusetts and Rhode Island beach representatives to find sponsors for this project. In doing so, the team uncovered accessibility and implementation needs in certain communities.

Table 1 lists the contacted individuals who addressed the presence of accessibility in their areas. The contacts listed below are members and organizations in their communities that aided the team in developing a professional accessibility design.

Table 1. Individuals and organizations contacted by the team regarding the project.

Name	Titles/organization
Susan Green	Beach Management Director of Hull Beach
Jason Burtner	South Shore Regional Coordinator at Massachusetts Office of Coastal Zone Management
Friends of Lynn and Nahant	Non-Profit organization of Lynn Shore and Nahant Beach
Kathryn Glenn	North Shore Regional Coordinator at Massachusetts Office of Coastal Zone Management
Kevin Conway	Head of Department of Conservation and Recreation (DCR) Nantasket Beach Reservation
Gina Purtell	Director of South Coast Sanctuaries at Massachusetts Audubon
Misty-Anne Merald	Senior Endangered Species Review Biologist at Massachusetts Division of Fisheries and Wildlife of the National Heritage and Endangered Species Program (NHESP)
Julia Godtfredsen	Newburyport Conservation Agent
Sue MacCallum	Duxbury Program Specialist
Bradford Bower	Duxbury Coastal Ecology Program Coordinator
Darryl Forgione	DCR Regional Engineer
Thomas McCarthy	Universal Access Director
Rachael Lee	Universal Access Associate Director

Julia Godtfredsen, a Newburyport Conservation Agent and Sue MacCallum of Duxbury Beach Reservation were determined as sponsors because Newburyport and Duxbury Beach Reservation were two locations with ongoing accessibility and conservation projects that aligned with the team's goals. Both sponsors were interviewed to better understand the needs and characteristics of the beaches.

After meeting with Julia Godtfredsen, potential pathway locations at Newburyport were identified as applicable to the project. Additional information was found regarding current dredging and dune nourishment projects. Information related to the ecosystem and unique characteristics of the beach were provided to the team, including endangered species totals and various environmental and regulatory hindrances.

Additional contacts and resources were also provided to shape the Newburyport project scope. Julia Godtfredsen referred the team to Department of Conservation and Recreation (DCR) regional engineer Darryl Forgione, who helped the team better understand the layout of the

beach, past projects in the area, and provided an engineering perspective for materials and mechanisms. Additional correspondence and meetings with him followed as the project matured into a specific design focus and implementation.

Meetings with Sue MacCallum were also conducted to learn more about Duxbury Beach Reservation. Sue MacCallum was an invaluable resource for learning about the functionality of the beach and its conservation related to Piping Plovers that live there. Sue MacCallum also identified specific areas for accessway projects and expressed enthusiasm for the design considerations. The history of sand dune movement was also discussed as the beach had undergone damage from erosion and other nature implications.

Additional contacts and resources were also provided to shape the Duxbury project scope. Sue MacCallum referred Bradford Bower who was knowledgeable of sand nourishment projects involving a potential passageway location. This was important to know for the feasibility and implementation stages of the design. This also included issues regarding the constructability of the space. Bradford Bower also provided ample background and historical information on the reservation as well.

Julia Godtfredsen, Darryl Forgione, Sue MacCallum, and Bradford Bower all posed many questions to the team and provided helpful and technical information related to their respective beach environments. Their expertise was used to aid the team's recommendations for the passageway materials and designs.

Members of the DCR Universal Access Program helped the team with additional aspects of accessibility. The Universal Access Program is an organization aimed at providing recreational opportunities for people of all abilities. Thomas McCarthy and Rachael Lee, the director and associate director of the program respectively, shared with the team the various accessibility regulations and implications of passageway designs (see Appendix B).

3.1.2 Independent Research

To better understand the process and factors that affect beach accessibility, literature reviews were conducted. Information regarding sand dunes, Piping Plovers, and additional environmental factors was collected to better understand the existing conditions on these sites. Therefore, the obstacles in design could be easily identified to inform the sponsors that the team's recommendations would include solutions around each of these factors. Prior information was collected to better understand the general environment of beaches; however, more information was found specifically related to the conditions of the Newburyport and Duxbury Beach Reservation sites.

Environmental conditions for both sites included the development and movement of sand dunes. To better understand how sand movement relates to passageways, several articles were reviewed to understand how construction can alter sand dune ecosystems. **Table 2** refers to all the articles researched around these topics. Full citations for these sources are available in the references section.

Table 2. Articles used for information on various passageway and sand dune topics.

Topic	Associated Sources
Sand Dune Potential Hurdles and Behaviors	○ Sample Landscape Plan for a Coastal Dune ○ The Importance of Sand Dunes to the Coastline ○ Why are Sand Dunes Important? ○ Dynamics, Threats, and Management of Dunes ○ How Sand Dunes Protect US
Sand Dunes Methods of Stabilization	○ What Is Dune Restoration? Why Is It Necessary? ○ Landscaping a Coastal Beach or Dune ○ Coastal Dune Protection and Restoration
Sand Dunes Permits and Legal Implications	○ Coastal Landscaping in Massachusetts – Do You Need a Permit? ○ Statutes, Codes, and Regulations
Erosion	○ What Causes Beach Erosion?
Endangered Species	○ Endangered Species Search by Area Selection ○ Piping Plovers Nesting In Beach Parking Lot ○ Piping Plover Rescue Hatched at Narragansett
Wetland Permits	○ Wetland permits ○ WetlandPermittingGuidance (1).docx
Best Management Practices	○ Best Management Practices - DCR ○ Beach Maintenance and Operations
Accessibility Constraints	○ What Makes For an Accessible Beach?
Laws and Regulations	○ Barriers at the Beach ○ Open Mass. Beaches to Everyone

Articles were reviewed for contact and used to supply additional knowledge of the conditions affecting Newburyport and Duxbury. Information was collected about vegetation and dune stabilization to understand what would best preserve the Newburyport and Duxbury Beach Reservation environments. This allowed better assessment of the current vegetation at each passageway location. Dune preservations have their own legal implications by use of permitting.

Additional readings provided details surrounding the historic use of beach grass, sand fences, and other vegetation that are applied to artificial dunes to aid in its natural replication. The management of sand dunes became an important scope of the project, which required additional literature review regarding how to protect these mounds.

Erosion was another environmental factor that was found to affect beach landscapes. It is important to consider all the native wildlife and ensure that their ecosystem is not impacted by invasive projects or species. To further understand this implication, many resources were found, including those from Narragansett Beach.

Information on the specific design requirements was found in state regulations. To understand each beach design's applicability, it was crucial to understand ADA regulations and other construction codes. Wetland permitting and other regulations surrounding beach ownership became useful for the construction planning of each passageway.

Developing a manner of best supplying a design was coupled with the ability to manage such decisions for future use. In order to best frame this idea, the DCR best management practices were analyzed. General constraints were researched with content regarding the amenities and additional characteristics that were required to support an accessible beach space. Information about the state of Massachusetts was investigated to uncover laws concerning beach characteristics.

3.1.3 Site Visits

Site visits were conducted at Newburyport and Duxbury Beach Reservation to collect more information regarding the beaches and current accessibility features. On each site visit, the team recorded observations and information to help in later design considerations. These site visits allowed in-person interaction with the beaches and conversations with stakeholders about their visions for the projects. The personal connection and experience with each beach and sponsor gave the project a more detailed outlook, meaning, and understanding.

3.2 Material Analysis

Additional research was conducted to understand the specific products and components of beach architecture. Various materials were analyzed through case study prevalence, expert recommendation, and material properties research.

3.2.1 Case Study Application

Invaluable case studies were found during the preliminary research stage and provided insights into material applications. Through this research, a select number of materials were chosen for further consideration.

3.2.2 Creation of Criteria

The team found six material properties that affect the performance of a structure. The six different properties were as follows:

- Stiffness (Modulus of Elasticity)
- Strength (Modulus of Rupture)
- Hardness
- Water Resistance (Slip Resistance)
- Heat Capacity
- Toxin Content

3.2.3 Comparison of Materials

Material recommendations consider the environment and ecosystems at Newburyport and Duxbury Beach Reservation. It was important to choose materials that would withstand the environmental conditions of each area. The criteria mentioned above (stiffness, strength, hardness, etc.) were recorded for the selected materials.

3.3 Develop Design

The recommendations for each preliminary design were created as a cumulation of methods 3.1-3.2.

3.3.1 Case Study Application

Alternate cases of specific designs were analyzed to understand the successes and failures of beach passageways. Conservation and accessibility efforts similar to this MQP in Gloucester (Winslow, 2020), Lynn (Burrell, 2022b), and Brewster (CZM, n.d.) were reviewed to help the team gain knowledge of ongoing projects in the same area. Additionally, past passageway plans were used to analyze previous successful designs that have been established.

Darryl Forgione and Bradford Bower supplied the team with images and plans that were analyzed and used to frame additional planning of the passageway designs. Darryl Forgione showcased his past projects to inform the team of what accessible designs were successful. Bradford supplied the team with plans of the elevations needed for the Duxbury Beach Reservation passageway design after the dune renourishment project is completed.

In further accessing the designs of alternate beaches and design plans alike, the team was able to assert the proper procedures and design elements that would be the most applicable. In determining these characteristics, cost was revealed to be an instrumental factor for the ability to assert a design as being feasible to construct for a given area. Multiple past projects and pricing plans were consulted to predict the associated costs of the recommendations. For the elevated wood structure, a memorandum of boardwalk plans from the town of Yarmouth, Massachusetts was used (Williams, 2018). In contriving the polyester mat pricing, the Mobi-mat site was referenced to estimate the cost of product (Wooden, n.d.).

3.3.2 Creation of Criteria

The passageway design mechanisms had their own criteria in understanding what attributes made them standout contenders. These criteria included all the issues that the designs for the passageway would face. The criteria listed was established to analyze the designs:

- Protection of Sand Dunes
- Sand Movability
- Endangered Species Impact
- ADA Compliance

3.3.3 Developing Preliminary Designs

Design constraints were explored to reveal the environmental impacts to surrounding ecosystems of the preliminary passageway designs. This was the first step to understanding the feasibility of the passageway application.

3.4 Evaluate Design

In this stage, the passageway designs were presented to stakeholders, industry experts, and the team's advisor to receive opinions and critical evaluations of the designs.

3.4.1 Presentation of Designs

A presentation was prepared and presented to both beach representatives simultaneously, giving them an opportunity to meet as well as exchange ideas and expertise. Feedback and tips were received about the viability of the passageway designs.

3.4.2 Modify Design

The feedback was applied to the designs and used to ensure better feasibility metrics, including key ideas and decisions from stakeholders.

3.5 Production of Recommendation

Following the last round of modifications, the designs were conceptualized using Computer Aided Design software AutoCAD for each location for the team to display their recommendations and create their final deliverable.

Chapter 4

Results

The following chapter presents the team's findings from research, interviews, and analysis that led to each location's final design recommendations.

4.1 Determination of Locations and Constraints

The team contacted several public and private beaches in Massachusetts and Rhode Island. It was determined that the team would be making recommendations for new, accessible passageways for both Duxbury Beach Reservation in Duxbury, Massachusetts and Newburyport Plum Island in Newburyport, Massachusetts as representatives from both locations expressed interest in working to improve beach accessibility. Each beach presented separate challenges and conditions, but the goal of accessible passageway recommendations was the same for both locations. Therefore, the team decided to analyze both sites.

4.1.1 Duxbury Beach Reservation

The goal for Duxbury Beach was to formalize a non-utilized parking lot and design an accessible path over the existing dune to connect the parking lot to the beach. A site visit to Duxbury Beach on November 9th, 2022, revealed the ideal location of the new desired passageway (**Figure 9**).

(a) (b)

Figure 9. Aerial imagery via Google Earth of desired passageway (circled in red) at Duxbury Beach Reservation (a) and photo of same location (b).

Representatives from Duxbury Beach met the team at the main parking lot (triangle 1 in **Figure 10**), to show the location of the main beach access point and highlight the specific areas in need of improvement further down the reservation. The team learned about the beach's existing conditions from this site visit and conversations with Reservation staff.

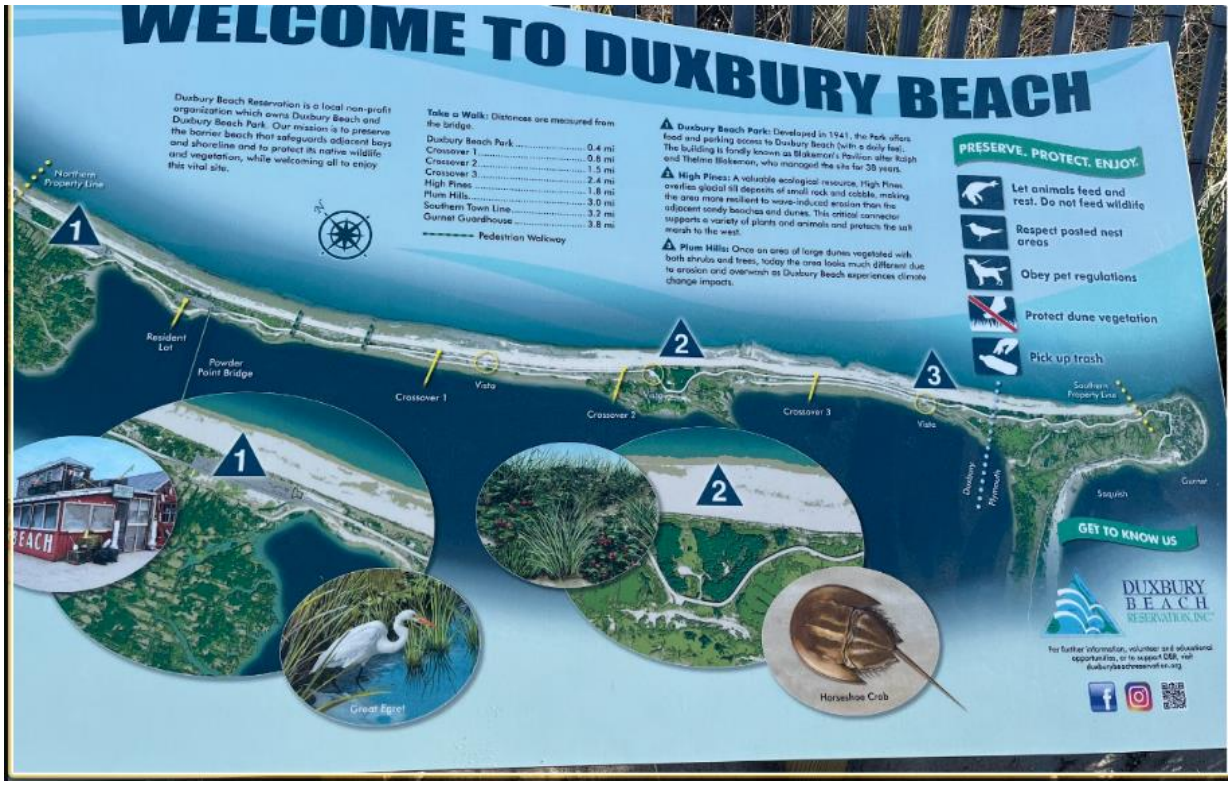
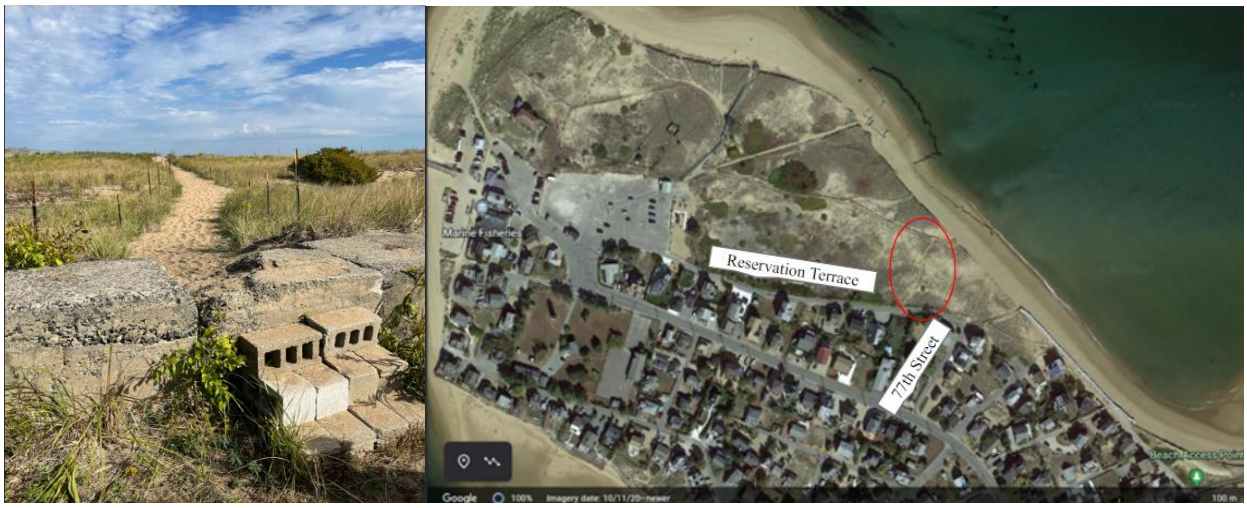


Figure 10. Map of Duxbury Beach Reservation.

The main area of interest during this site visit was the underdeveloped parking lot in triangle 2 (**Figure 10)**. The Duxbury Beach Reservation Program Specialist had expressed interest in this location for a passageway design since it would soon undergo a dune renourishment project that would increase the height of the dune to 16 feet in elevation.

4.1.2 Newburyport Plum Island

The goal for Newburyport was to formalize an inaccessible, unsafe desire path from Reservation Terrace to Plum Island Beach. The pathway connected Reservation Terrace to the beach (**Figure 11a & 11b**). It was considered a historical desire path that had not been fully formalized to compliance. There were cinder block steps that would be impossible for a person with mobility challenges or a wheelchair user to navigate.



(a) (b)

Figure 11. The desired pathway to be formalized in Newburyport, MA (a) and aerial view via Google Earth of the selected passageway (circled in red) at Plum Island (b).

The team, project advisor Suzanne LePage, and Coastal Engineer Nathan Dill visited Newburyport on October 7, 2022, walking along Reservation Terrace from the main parking lot to 77th street, and back along the beach. During the walk, the team saw many different passageways leading from the parking lot or main road to the beach, including some that were well-maintained and others that needed attention (**Figure 12**).

Figure 12. The former Newburyport pathway taken over by sand erosion.

At the beach end of the path, the sand was uneven and lacked handrails (**Figure 13**).

Figure 13. Pathway from Reservation Terrace to Plum Island beach where the path meets the beach.

The Newburyport Conservation Administrator mentioned that a sand dredging project was taking place on Plum Island between September 2022 and March 2023. Once the project is completed, the representative wants to pursue creating a new passageway on to the beach. This passageway would allow for new sand to freely would shift with the sand patterns and dunes, and benefit endangered species. Therefore, the team decided to focus on formalizing this passageway to ADA compliance as the main goal.

4.2 Design Constraints

Five categories, including site-specific constraints, were considered during the analysis of both designs and decisions of final design recommendations for both locations. (**Table 3**).

Table 3. General design constraints defined for both locations.

Environmental	Sustainability	Manufacturability	Economic	Accessibility
⋆ Preservation of existing habitats ◦ Sand dunes ◦ Piping plovers ◦ Other endangered spesices ⋆ Wind direction	⋆ Ease of mantinence ⋆ Durability in off-season ⋆ Erosion and weather resistance ⋆ Longevity of material and structure	⋆ Availabilty of materials ⋆ Ability to construct	⋆ Cost of materials, labor, installation, mantinence	⋆ Meeting ADA Standards ⋆ Accessible for all persons regardless of physical ability

4.2.1 Duxbury Beach Reservation Site Specific Constraints

The dune elevation and preservation of the existing dune habitat were crucial when considering the passageway design. The passageway must be atop a 16-feet high elevation to completely clear the dune, while still meeting ADA standards (**Background 2.5.3**).

4.2.2 Newburyport Plum Island Site Specific Constraints

Although the passageway is already defined and at-grade with the sand dunes, it was important to choose a design that would not disrupt the surrounding dunes or their shifting patterns, as dunes are vital in protecting nearby beachfront properties. High erosion rates, sand moveability, ADA compliance were all key constraints in the design so the passageway could change with the dynamic beach while remaining accessible.

4.3 Determination of Material and Mechanisms

The team narrowed down the ideal materials and mechanisms that would be used in the recommendations through conversations with industry experts, research, and analysis.

4.2.1 Comparison of Materials

The three materials evaluated and compared for the passageway design were Kebony wood, cedar wood and polyester. **Table 4** displays the comparison of the materials in terms of characteristics, mechanical and physical properties.

Table 4. Mechanical Property Comparison of Cedar, Kebony Wood, and Polyester.

Material	Wood		Polyester
	Eastern Red Cedar	Kebony	
Property			
Stiffness (Modulus of Elasticity)	1,700,000 psi (11.7 GPa)	1,798,468 psi (12.4 GPa)	493,563 psi (3.403 GPa)
Strength	8,800 psi (60.7 MPa)	4,930 psi (34.0 MPa)	25,500 psi (175.84 MPa)
Hardness	900 lbf (4 kN)	1618 lbf (7.2 kN)	1450 lbf (6.4 kN)
Water Resistance (Slip Resistance)	Resistent to extremes of drought, heat, and cold	Classification A, 12"-17" barefoot walkways, mainly dry	USMC approved and salt-water resistant
Heat Capacity	160 °C	180-230 °C	X
Toxin Content	Non-toxic to touch	Moderately toxic OSHA hazard training = 3.3 with probable lethal dose to humans being 0.5 - 5 g/ kg	Releases toxic chemicals and greenhouse gases to the environment when breaks down. However, recycling PET grade plastic into higher quality fabrices reduces pollution, reduces landfills, and likelihood of plastic incineration (which releases toxic gases into atmosphere).

4.2.2 Comparison of Mechanisms

Two passageway designs were developed and evaluated to best fit the needs of each location: an at-grade polyester roll-out mat and an elevated wood structure. **Figure 14** shows the key factors of each design.

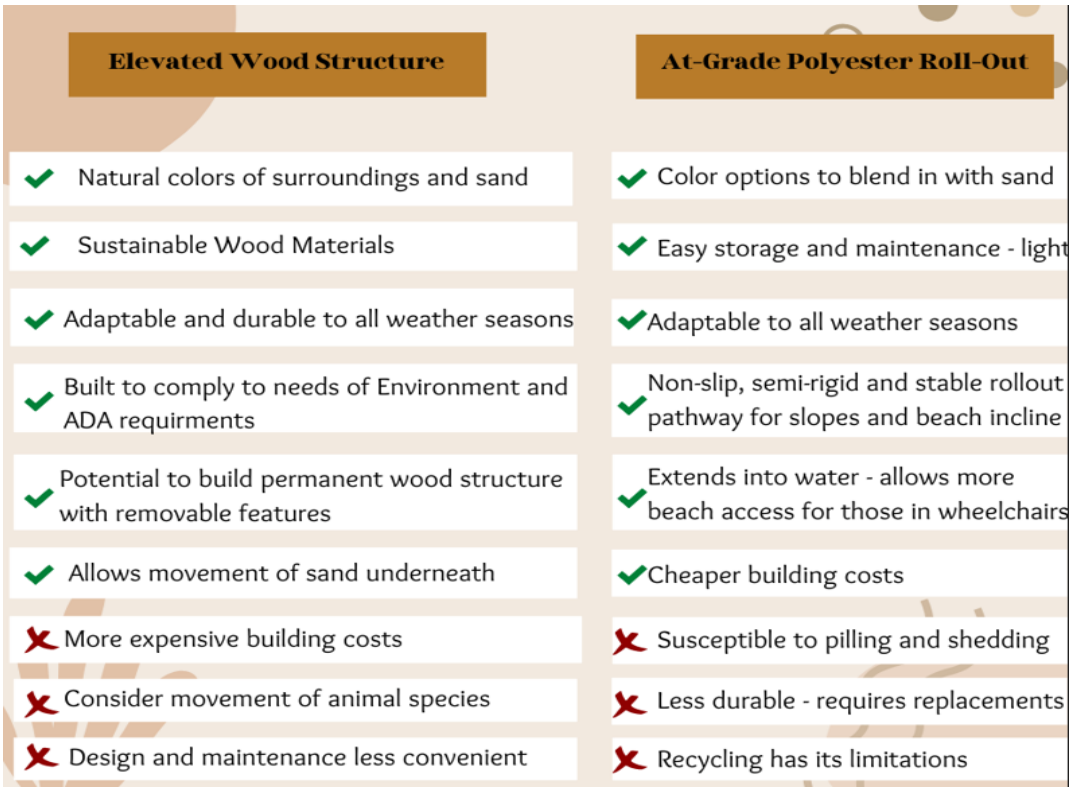


Figure 14. Comparison of Elevated Wood Structure and At-Grade Polyester Roll Out.

The main advantage of the elevated wood structure is that it allows for the natural movement of sand dunes and habitat life beneath the structure, and the pilings necessary for stability that only cause a minimal disturbance to the habitats below. The main advantage of the at-grade polyester roll-out style is that it is easily removeable for off-season and inclement weather and can be adjusted for changing tide and sand levels.

Chapter 5

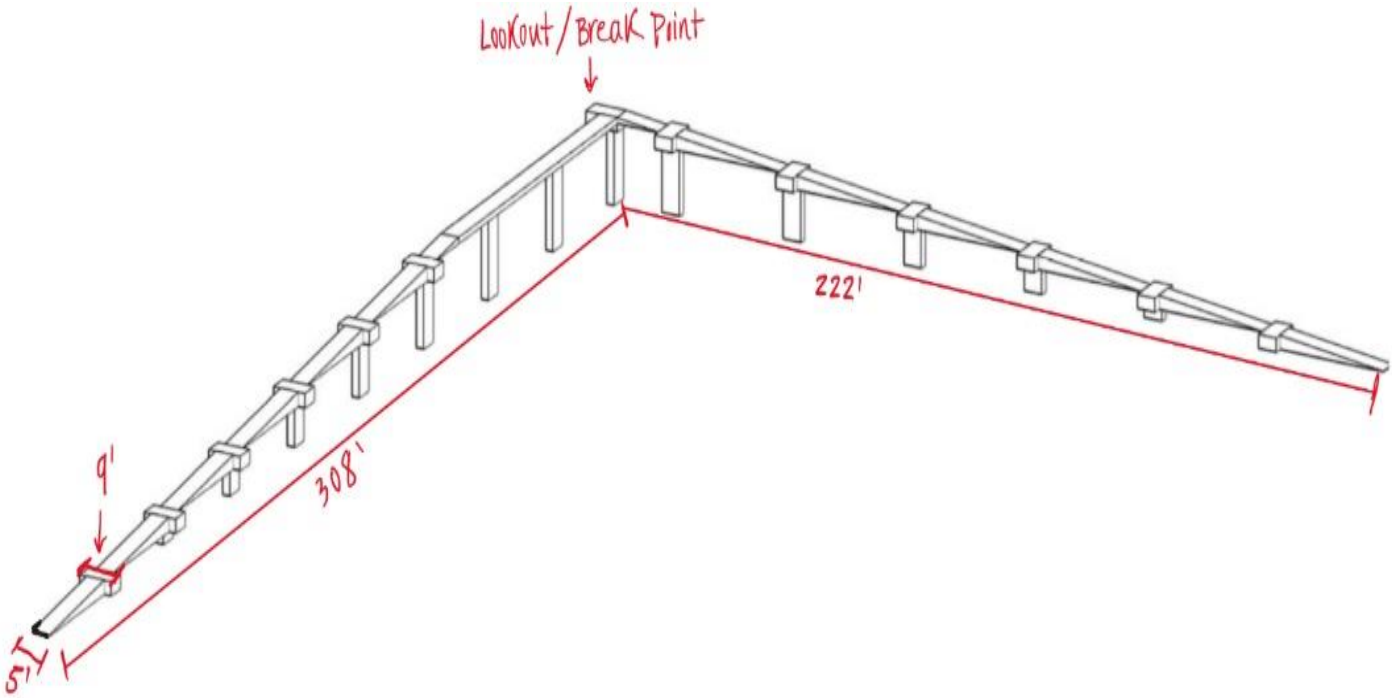
Recommendations

The team formulated recommendations and future steps for each location through analysis of our findings and conversations with stakeholders. For implementation to each location, the team recommends reaching out to local technical or vocational high schools to assist with the construction and manufacturing materials or structures. For funding at each location, the team also recommends looking into local community grant programs, such as the Institution for Saving Charitable Foundation or similar programs (*Institution for Savings*, n.d.). These grants may cover the costs of materials and inviting the help of vocational or technical high schools may alleviate the costs of labor and maintenance.

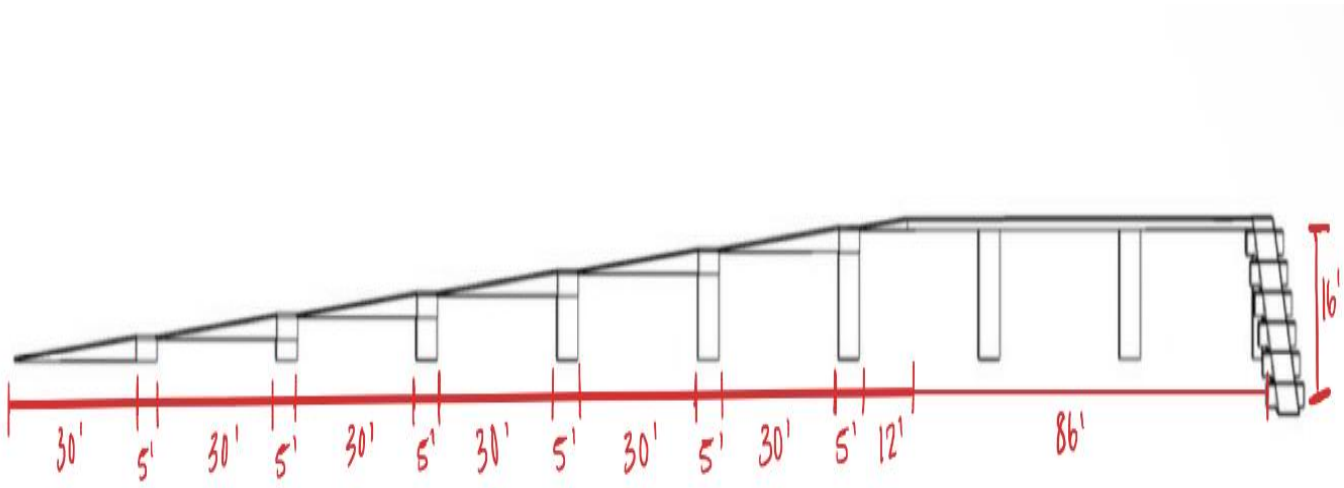
5.1 Duxbury Beach Reservation

The team recommends an accessible, elevated Kebony wood passageway structure that would lead onto the beach from the parking lot at Crossover 2. The location of Crossover 2 is marked by triangle 2 in the **Figure 10** map of the Duxbury Reservation. Kebony was chosen for its robust properties and its frequency of use in beach construction. The team also recommends the parking lot be utilized for non-permit based public parking, to provide more opportunities for the public to enjoy the beach.

The passageway will need to achieve a height of 16 feet to properly traverse over the newly renourished dunes. To reach a height of 16 feet with a proper ADA slope of 1:12 (8.33%), there must be 192 horizontal feet of length of inclined passageway. In order to comply with ABA (Architectural Barriers Act) standards, an inclined ramp of 8.33% can only extend 30 feet before a minimum 5 feet x 5 feet resting area must be present (U.S. Access Board, 2023). The team recommends an 8.33% slope with 5 feet x 9-feet resting areas placed every 30 feet until the desired height of 16 feet is reached at 222 feet of horizontal length (**Figure 15**).



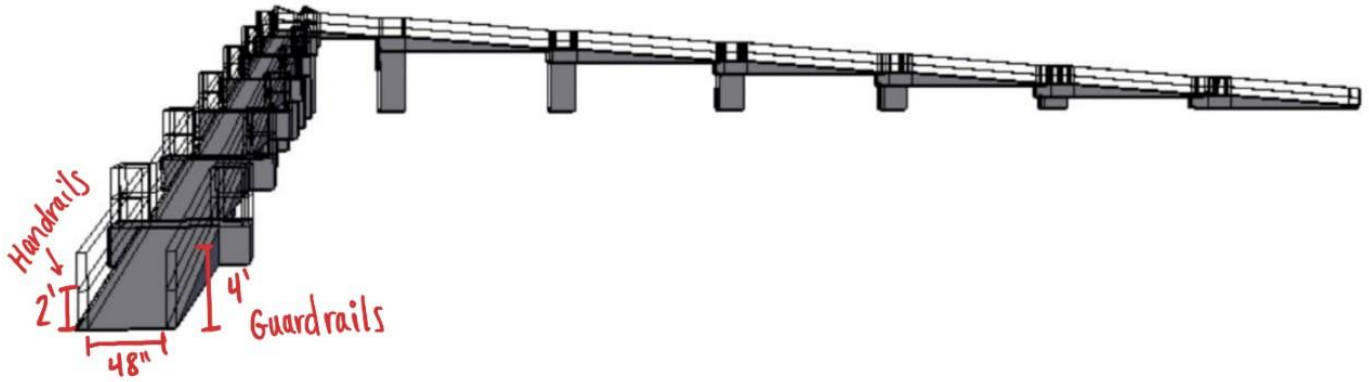
(a)



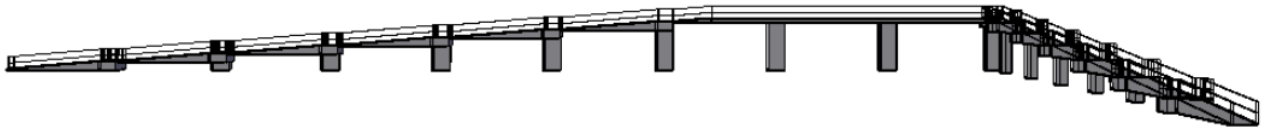
(b)

Figure 15. Isometric view (a) and side view from parking lot to beach (b) of recommended passageway design for Duxbury Beach.

In accordance with state and federal accessibility standards, handrails and guardrails must be added to the entirety of the structure (DCR Universal Access, Personal Communication, February 2023). The team recommends adding wood guardrails at a height of 4 feet above the slope along the entirety of the structure, with handrails at 2 feet above the slope (**Figure 16**). The guardrails should be ½ inch in thickness, leaving 48 inches between the handrails, in accordance with state guidelines.



(a)



(b)

Figure 16. Recommended structure with handrails from entrance view (a) and side view (b).

The total horizontal distance from the parking lot to the beach is 308 feet. After the 222 feet of horizontal length required to adequately reach a height of 16 feet, the remaining 86 feet will be a flat surface that leads to a lookout point of Duxbury Beach. This will be followed by a similar down-slope structure that will lower onto the beach at a slope of 8.33% with 30 feet increments and 5 feet by 9 feet resting areas. The passageway will extend in the southern direction, opposite of the natural northernly wind patterns. **Figure 17** shows the location and orientation of the recommended design.

Figure 17. Proposed location and orientation of the elevated wood structure.

In terms of implementation, the team recommends that this work be passed off to a future WPI MQP team that will complete a full structural analysis of the structure. A future MQP team may also be utilized to design a mechanism that would allow moveable parts of the structure for the off-season, or as a necessity for climate change and shifting sand dune patterns. **Table 5** shows an estimated cost breakdown for the elevated wood structure including guardrails and handrails, based off a similar design in Yarmouth, MA (Williams, 2018).

Table 5. Estimated costs for Duxbury wooden design recommendation.

	Yarmouth Case Study	Duxbury Reservation
Length of Passageway (ft)	1490	882
Construction Costs (Material)	$1,760,456	$1,042,095
Developmental Costs (design/permitting/labor)	$275,500	$163,081
Total	**$2,090,456**	**$1,237,437**

5.2 Newburyport Plum Island

The team recommends an at-grade polyester roll-out style passageway to formalize the 230 feet of the existing path in Newburyport. The passageway is already at-grade and carved out of the natural movement of the dunes, therefore an elevated structure is not needed. For accessing the mat, the team recommends removing the cinder blocks between the pathway and Reservation Terrace **(Figure 11a & 11b)**, and instead, replace it with a moveable barrier during the winter months. The barrier may be removed during the peak season, and the polyester roll-

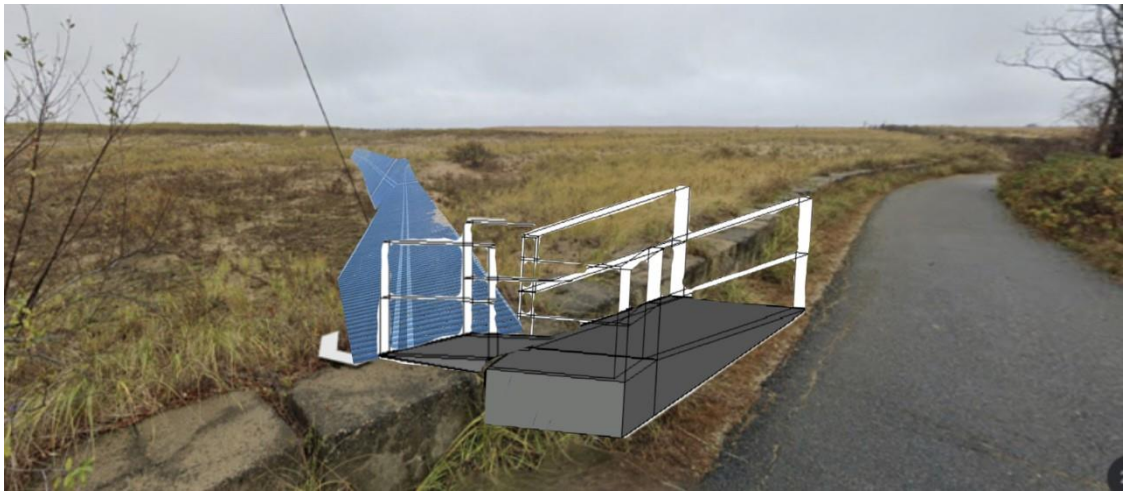
out mat will lead right on to Reservation Terrace for easy access. The pressure of the polyester mat, and the careful placement and moveability of the sand, will allow for an adequate ADA compliant slope from the road to the mat.

The concern of storm flooding or sand erosion if the cinder block is removed is mitigated by potentially adding floodgates at the entrance to the passageway. The product FlashWall by AquaFence® (**Figure 18**) is a protection barrier for a flashflood that may be deployed and disassembled by a single person in a matter of minutes (AquaFence, 2023). This barrier is portable, durable, and highly rated in industry use against flooding. FlashWall is 20 inches in height and base width, and ranges from 4 feet to 9.75 feet in length. Although its primary function is to prevent flooding, this technology is also used to minimize shifting sand and erosion to Reservation Terrace during a torrential weather event. The team recommends that FlashWall, or a similar barrier, is implemented at the entrance of the pathway in place of the cinder block during storms and the off-season.

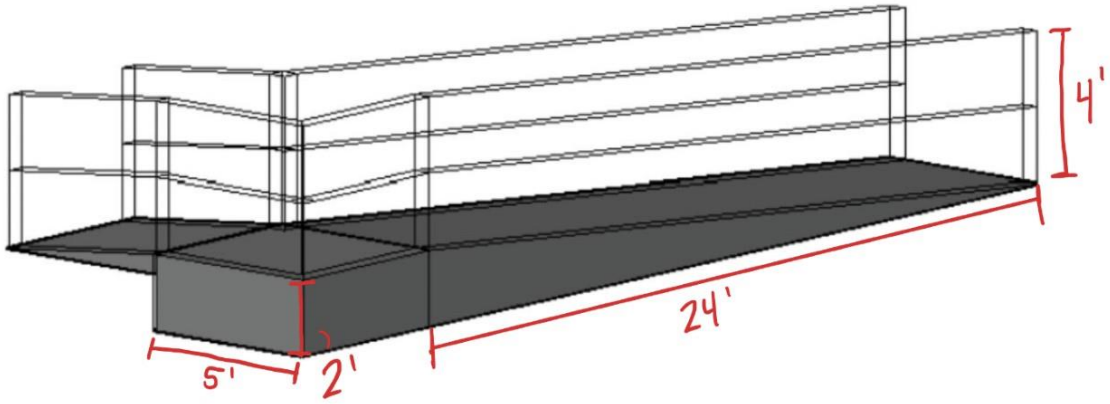
Figure 18. FlashWall by AquaFence® protects against sand erosion and flooding.

The base of the FlashWall is 20 inches and must be properly placed in order to avoid obstruction to a snowplow in the winter months. Since the FlashWall will serve as a replacement for the cinderblocks, it should be situated so that the end of the base is in line with the end of the cinderblocks on either side, so that a snowplow would not run over or place snow on to the base and damage it.

If it is not possible to remove the cinder blocks, the team recommends adding an ADA compliant ramp running parallel to Reservation Terrace along the path of the cinderblocks, rising over them, and leading up to the polyester roll out mat (**Figure 19a**). The ramp would need to comply with ADA standards of 1:12 (8.33%) slope and to reach a height of approximately 2 feet, it would need to run 24 feet long, parallel to Reservation Terrace (**Figure 19b**).



(a)



(b)

Figure 19. Proposed ramp that would lead directly onto roll-out polyester mat if removing the cinder block is not possible (a). Proposed ramp runs parallel to Reservation Terrace with a length of 24 feet (b).

There are several polyester roll-out designs on the market for beach access including the Mobi-mat® and AccessMat®. The team recommends using the Mobi-mat® brand for the Newburyport passageway due to its durability, reliability and use of recycled material. However, the downside of the Mobi-mat is that it does not bend to curves. Since the pathway is curved, the team recommends taking measurements and ordering a custom length, curved mat. Custom orders are available through the Mobi-mat® website via the "Contact Us" feature.

The maintenance of this recommendation will require careful execution to ensure the longevity of the materials. Mobi-mat® should be stored carefully laying on its side in a completely covered storage area, as standing on either end will leave it exposed to the elements, causing fraying. Deployment and recoiling of the mat will require two people who can carry significant loads. It will take approximately one hour to configure, and those in charge should consider raking the sand pathway before the mat is laid so the ground is even and clear of debris.

If the ramp over the cinder blocks is utilized, the team recommends the assistance of another WPI Civil Engineering MQP team to perform the structural analysis of the structure. The

Civil Engineering team will also need to coordinate the custom dimensions and associated costs, and further investigate the feasibility of a FlashWall. **Table 6** shows an estimated cost breakdown for the Mobi-mat design recommendation (Wooden, n.d.).

Table 6. Estimated material costs for Newburyport Mobi-mat design recommendation.

	Price per 50 ft	Price per path length (463 ft)
Mobi-mat ® cost	$2,219	$20,548

Chapter 6

Conclusion

Everyone deserves the right to inclusive and safe beach infrastructure, regardless of physical ability. Many people have difficulty navigating the inconsistent sandy terrain while using a wheelchair, walker, or pushing a stroller. Ideally, human beach access should be minimally disruptive to the natural environment. This project has addressed these issues for various beach conditions by recommending different passageway designs.

Our proposed solutions provide people with a designated path to the beach while minimizing disruptions to sand dunes and living species. Our solutions considered the sustainability and constructability of physical pathways, including each material's resistance to erosion and ease of maintenance. In an effort to create equitable and inclusive designs, both proposed passageways meet ADA requirements, including slope, width, hand and guardrails. A cost estimate was provided for both beaches to address economic design constraints.

The continuation of this project requires a structural design to be created and constructed in accordance with our recommendations. This includes the structural analysis of the elevated passageway at Duxbury Beach Reservation and a further investigation of the best possible removable design mechanism that will protect the structure against harsh weather conditions. In Newburyport, the continuation of this project will include customizing the Mobi-mat to the length and curves of the existing passageway and further investigating the best method of removing the cinderblocks to gain access to the mat itself. Although the implementation of these passageways are limited by the need for a complete design, this project contributes fundamental information towards its development. Our proposed materials and locations, as well as cost estimates and dimensions, provide a starting point towards improving beach accessibility in Newburyport and Duxbury.

These recommendations will provide Newburyport and Duxbury communities one day with additional beach accessibility and conservation to their rapidly eroding terrain. Although we have provided design considerations for only these two Massachusetts beaches, the design constraints remain consistent for other beaches and coastal areas. Therefore, our analysis and design recommendations are applicable to other coastal regions to further expand inclusive beach access.

References

Accessible beaches. Mass.gov. (n.d.). https://www.mass.gov/service-details/accessible-beaches/.

ADA National Network. (2023, January 31). *What is the Americans with disabilities act (ADA)?* ADA National Network https://adata.org/learn-about-ada/.

AquaFence. "FlashWall." *AquaFence Flood Protection*, 2023, www.aquafence.com/flashwall.

Beach wheelchairs. (2023, January 9) Mass.gov. https://www.mass.gov/info-details/beach-wheelchairs/.

Backman, A. (n.d.). *Best management practices - DCR*. Mass.gov. https://www.mass.gov/info-details/best-management-practices-dcr/.

Bellman, H. (2022). *Piping Plover program*. DNREC Alpha. https://dnrec.alpha.delaware.gov/fish-wildlife/conservation/piping-plovers/.

Beach Maintenance and Operations. DCR Massachusetts. (2015, March). https://www.mass.gov/doc/beach-maintenance/download/.

Botelho, J. A. (2018, June 8). Piping plovers nesting in beach parking lot. WJAR. https://turnto10.com/news/local/piping-plovers-nesting-in-beach-parking-lot/.

BraunAbility. (2021). *What are the Ada Ramp Requirements*. BraunAbility. https://www.braunability.com/us/en/commercial/white-papers/.

Burrell, C. (2022a, July 25). Barriers at the Beach: People Tussle over scarce beach access as sea levels and property values rise. *GBH News*. https://www.wgbh.org/news/local-news/.

Burrell, C. (2022, November 11). *Barriers at the beach: State law and town rules keep most of Mass. Shoreline Off-limits*. GBH News. https://www.wgbh.org/news/local-news/.

Burrell, C. (2022b, September 2). Historic racism still raises barriers to beach access. *GBH News*. https://www.wgbh.org/news/local-news/2022/09/02/historic-racism-still-raises-barriers-to-beach-access/.

CARO. (n.d.). How sand dunes protect us. CARO. https://www.caro.ie/projects-research/campaigns/sand-dune/they-protect-us/.

Casetext Inc. (2021). *Statutes, Codes, and Regulations*. Legal research tools from Casetext. https://casetext.com/regulation/code-of-massachusetts-regulations/department/.

Commonwealth of Massachusetts. (2023). Sample landscape plan for a coastal dune. Mass.gov. https://www.mass.gov/service-details/sample-landscape-plan-for-a-coastal-dune/.

Commonwealth of Massachusetts. (n.d.). *Landscaping a coastal beach or Dune*. Mass.gov. https://www.mass.gov/service-details/landscaping-a-coastal-beach-or-dune/.

Commonwealth of Massachusetts. (n.d.). *Coastal landscaping in Massachusetts - do you need a permit?* Mass.gov. https://www.mass.gov/service-details/coastal-landscaping-in-massachusetts-do-you-need-a-permit/.

Cornell University. (2020, April 26). Heading to the shore.... Heading to the shore.... | The Northeast ADA Center. https://northeastada.org/blog/heading-to-the-shore/.

Darlington, A. (2016, November 2). *Making beaches accessible to disables, an uphill battle for authorities*. Post and Courier. https://www.postandcourier.com/archives/.

Deschamps Mats Systems Inc. (2020, June 30). MAT® ADA beach access mat™ inclusive technology. 5′ and 6.5′ ADA roll out Access Mat. https://www.mobi-mat-chair-beach-access-dms.com/ada-roll-out-walkway-access-mat/.

Division of Fisheries and Wildlife. (2022). *Mass Wildlife's Natural Heritage & Endangered Species Program.* Mass.gov. https://www.mass.gov/orgs/masswildlifes-natural-heritage-endangered-species-program/.

Duxbury Beach Reservation, Inc. (2019). Facts about Duxbury Beach. Duxbury Beach. https://www.duxburybeachreservation.org/facts/.

Endangered Species Search by area selection. Earth's Endangered Creatures. (n.d.). http://www.earthsendangered.com/searchregions/.

England, R. (2021). *Why are sand dunes important?* OneHome. https://onehome.org.uk/the-bigger-picture/424-why-are-sand-dunes-important/.

Gurley, G. (2015, July 7). Plum island at risk. *CommonWealth Magazine*. January 19, 2023, https://commonwealthmagazine.org/environment/plum-island-at-risk/.

GZA GeoEnvironmental, Inc. (2021). Notice of Intent Application: NFS Permitting of Dredge Spoil Beneficial Use. Plum Island Reservation, Newburyport, Massachusetts.

Heurtefeux, H., Milor, M., Bichot, A., & Grosset, S. (2021, October 8). *Dynamics, threats, and management of dunes.* Marine Species Wiki. https://www.marinespecies.org/introduced/wiki/Dynamicthreatsandmanagementofdunes/.

How dune restoration prevents beach erosion. Superior Groundcover. (2021, February 24). https://www.superiorgroundcover.com/dune-restoration-how-dunes-prevent-beach-erosion/.

Howard, M. (2022, August 11). *Open Mass. beaches to everyone - with buses - the Boston GlobO*. Boston Globe. https://www.bostonglobe.com/2022/08/11/opinion/open-mass-beaches-everyone-with-buses/.

Importance of sand dunes to the coastline. (2022). SurferToday. https://www.surfertoday.com/environment/.

Institution for Savings. Charitable Foundation | MA Grants | Institution For Savings. (n.d.). https://www.institutionforsavings.com/charitable-giving/.

Jesse, J. (2008, December 17). *What Causes Beach Erosion?* Scientific American. https://www.scientificamerican.com/article/what-causes-beach-erosion/.

Kuffner, A. (2018, June 12). *Piping plover rescue hatched at Narragansett Beach*. The Worcester Telegram & Gazette. https://www.telegram.com/story/news/environment/.

Malones, L. (2018, September 3). *What makes for an accessible beach? we asked wheelchair users how they plan a day by the water*. MIC. https://www.mic.com/articles/191053/.

Massachusetts Department of Conservation and Recreation (DCR). (2015, March). *Beach Maintenance and Operations.* Mass DCR Office of Regional Planning. https://www.mass.gov/doc/beach-maintenance/download/.

Massachusetts Department of Environmental Protection. (2022). *310 CMR 10.00: Wetland Protection Act.* Mass.gov. https://www.mass.gov/regulations/310-CMR-1000-wetlands-protection-act-regulations/.

Massachusetts Office of Coastal Zone Management (CZM). (n.d.). *Brewster: Relocation of Vulnerable Infrastructure*. Mass.gov. https://www.mass.gov/service-details/brewster-relocation-of-vulnerable-infrastructure/.

Massachusetts Office of Coastal Zone Management. (2022). CZ-Tip - Basics of Building Beach Access Structures that Protect Dunes and Banks. Mass.gov. https://www.mass.gov/service-details/cz-tip-basics-of-building-beach-access-structures-that-protect-dunes-and-banks/.

Miller, D. (2022, February 16). Mobility mats are coming to Clearwater Beach. this resident hopes more beaches will follow suit. WUSF Public Media. https://wusfnews.wusf.usf.edu/health-news-florida/.

Mobility Mats - Tampa Bay, Florida. Help Us Gather - HUG. (2022, September 9). https://helpusgather.org/mobilitymats/.

NSRWA. (2022, July 23). Duxbury Beach Reservation. North and South Rivers Watershed Association. https://www.nsrwa.org/listing/duxbury-beach-reservation/.

O'Connell, J. (2008, December). *Using 'cape' American Beachgrass & Fencing - Mass.gov*. Mass.gov. https://www.mass.gov/doc/coastal-dune-protection-and-restoration-using-cape-american-beachgrass-and-fencing/download/.

Oktay, S. D. (2013, June 20). Coastal Beach Processes & Erosion. *Yesterday's Island, Today's Nantucket*. January 19, 2023, https://yesterdaysisland.com/coastal-beach-processes-erosion/.

Plum Island Beach. (2022). Newburyport.com. https://www.newburyport.com/plum-island-beach/.

Rogers , D. (2022, October 11). Plum Island Dredging Project just days away. The Daily News of Newburyport. https://www.newburyportnews.com/news/.

Scientific American. (2008, December 17). *What causes beach erosion?* Scientific American. https://www.scientificamerican.com/article/what-causes-beach-erosion/.

Seccombe, M. (2008). *Against odds, Piping Plovers rebound*. The Vineyard Gazette - Martha's Vineyard News. https://vineyardgazette.com/news/2008/06/05/against-odds-piping-plovers-rebound/.

Stone Living Lab. (2022, January 21). The Duxbury Beach Reservation creates nature-based approaches to address erosion. Stone Living Lab. https://stonelivinglab.org/news-article/duxburyerosion/.

SurferToday. (n.d.). The importance of sand dunes to the coastline. Surfertoday. https://www.surfertoday.com/environment/the-importance-of-sand-dunes-to-the-coastline/.

Van Buskirk, C. (2021, November 30). Panel aims to ensure Massachusetts public beaches are accessible to all. *MassLive*. https://www.masslive.com/news/2021/11/panel-aims-to-ensure-massachusetts-public-beaches-are-accessible-to-all.html/.

Vinelli, R. (2000). *Charadrius Melodus (Piping Plover)*. Animal Diversity Web. https://animaldiversity.org/accounts/Charadrius_melodus/.

Webber, A. F., Heath, J. A., & Fischer, R. A. (2013). Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during the breeding season. *Ecology and Evolution*, *3*(4), 853–863. https://doi.org/10.1002/ece3.511/.

Williams, K. (2018, February 9). Memorandum. South Yarmouth, Massachussets; 1146 Route 28.

Winslow, S. (2020, July 9). Ambassador Group Works to Protect Gloucester's Endangered Piping Plovers. *Northshore*. https://www.nshoremag.com/faces-places/ambassador/.

Wooden like walkway, blue, Brown Beach Sand Pathway Mat & Boat launch. Mobi-mat. (n.d.). https://shop.mobi-mat.com/.

Appendices

Appendix A: Project Proposal

Implementing an Accessible Walkway and Piping Plovers Dune Conservation in Plum Island and Duxbury Beach Reservation

Nadiya Chalak, Caitlin Coumounduros, Madison Garrity, and Colette Webster

WORCESTER POLYTECHNIC INSTITUTE

Advisor:

Suzanne LePage

Project Capstone Design Statement

WPI requires all students to complete a capstone design project, which is known as the Major Qualifying Project (MQP), as one of its graduation requirements. This project meets the capstone design requirement by providing beach access to beachgoers on Plum Island and Duxbury Beach through the design of an accessible passageway catered to each location. Accessibility to our team is defined as equitable to all persons regardless of disability, physical limitations, or mobility. Vulnerable ecosystems, including piping plovers, sand dunes, and other natural beach habitats will be considered in the design and implementation of the passageway to both locations.

On Plum Island, located in Newburyport, MA, the passageway will travel through newly replenished sand dunes giving beachgoers a clear path of where it is safe to cross without disrupting the surrounding environment. This passageway will travel from 77th Street to the beach, and from 77th to 73rd street, connecting the dune habitats that break up Reservation Terrace. On Duxbury Beach Reservation, in Duxbury, MA, the passageway will consider avoiding piping plover nesting and preserving sand dune habitats.

Our project will evaluate the design criteria and associated environmental implications to determine the best methods for accessible beach passageway construction that will be specified and most beneficial to both Plum Island and Duxbury Beach Reservation. Listed below are constraints that will be considered during the progression of our design:

- Economic
    - Available funds for beach construction
    - Taxpayer concerns
- Environmental
    - Constructing around vulnerable ecosystems, including but not limited to, piping plovers, sand dunes, and beach grass
    - Maintaining the natural movement of the sand dunes
- Social
    - Abutters concerns - neighbors in close proximity to the design may not approve or agree with the addition of a passageway in close proximity to their property
- Political
    - Massachusetts waterfront laws state that property owners on coasts own from their property line up to the high tide line
        - If the passageway is implemented on private property, owners could get involved with local government
- Ethical
    - Determining which aspects are most important to protect
        - The dunes for protection to property
        - The piping plovers and endangered species habitats
        - Beachgoers access to the beach
- Health and safety

    - Ensuring the passageway is wheelchair compliant and safe for all-persons usage
    - Health of the piping plover habitat during and post construction
- Manufacturability
    - Access to materials and labor
    - Feasibility of implementation to current conditions
- Sustainability
    - Maintaining the passageway throughout the winter months
    - Ensuring durability of the passageway to survive storms, rising tides, and sand erosion
    - Proper materials that will not be harmful to surrounding ecosystems

Table of Contents

Chapter 1

Introduction

Earth is a planet constantly changing. From the wind and rain of the heaviest storms, the earth's surfaces shifting, and the ocean's mighty waves, the world as we know it never remains the same for too long. Sea levels rise, land is swept to sea, and the earth is pounded away to destruction. Every year immense efforts are exerted to continue replenishing the land and shore to preserve the places that humanity has grown to love, adore, and call their own. Humans often forget however that the largest threat to their home landscape is themselves.

Climate change has caused catastrophic effects on coastal conditions. The rising temperatures have caused sea levels to rise and wave patterns to become more dramatic and destructive. In Massachusetts, these issues are highly problematic to the natural and manmade environment. With over 53% of the Massachusetts population residing in coastal communities, the shrinking shores are backyards that are disappearing (Sea, 2022).

Carbon emissions and other side effects of the human footprint are attributed to the melting of the ice caps and volatile changing weather conditions (Toimil et al., 2020). Constant upkeep of coastal conditions needs to be continued as climate change continues to alter the seas and weather's behavior. It would be much easier to allow these beach destinations to be swallowed by the sea and better fortify the coastal neighborhoods and infrastructure than investing in this expensive replenishment cycle.

The sandy shore does however play a vital role in preventing the destruction of infrastructure. This is why sand dunes stand as an integral part of the solution to protecting against coastal erosion. These large mounds prevent the ocean waters from traveling up shore into nearby infrastructure. When storms creep in towards shore, the dunes are the last line of defense against the high surge, erosive waves (Patten, 2016). The water is absorbed and stopped by the large mounds.

Issues arise when these mounds become damaged and torn apart. While waves and winds do their part to tear down the dunes during inclement weather, the leading destroyers of these coastal protectors are humans. To mitigate the destruction of such, beach access could be closed to foot traffic to allow for the beach to do its part and protect our homes. Much less preservation methods would need to be exercised, and the size of the dunes could be exaggerated more to serve as even more rigid, sturdy defenses since humans would no longer need to navigate over and through them to the shore.

Beaches have established themselves well into the lives of people all over the world. Whether it is a family beach vacation, a day trip with friends, or even a quaint area to go fishing, the shore has become such an important part of human life that their access will never be able to be stripped away. Instead, other measures need to be exerted to save the dunes that will not strip the public of their desire and right to enjoy their favorite seasonal hideaways.

In order to preserve these dunes and the coastline that has become such a beloved part of the Massachusetts family, different measures can be taken like regular preservation work, planting sea grass, and erecting fencing. One measure that not only helps with steering foot traffic away from dunes but also protects animal habitats and allows all visitors a safe easy route to their favorite shoreline spots is constructing clearly defined passageways.

These passages will supply people with clear spaces to maneuver to the beach comfortably without any immense destruction to dune structures and animal habitat disturbance. A common species habitat that is often bombarded by human interaction is the Piping Plover. This species requires space of its own to grow and prosper as a bird. Space to themselves away from human interference is the greatest struggle endured that causes the most issue with these birds.

This project aims to solve these issues related to dune preservation and the safety of animal habitats to remove humans further from the equation of destroying the surrounding ecosystems. The specific scope defined is two beach locations in Massachusetts: Plum Island and Duxbury beach. Both locations have identified needs in these areas and desire passageways to simplify access to their beaches and the movement of people. Our goal is to design an accessible passageway for all beachgoers on Plum Island and Duxbury Beach that protects and preserves its landscape while considering these sand dunes and piping plovers.

Chapter 2

Background

This chapter provides the context behind Plum Island and Duxbury Beach Reservation, conservation of sand dunes and Piping Plovers, accessibility onto beaches, and recommendations regarding conservation and accessibility which are referenced and built upon in our project.

2.1 Context

This section introduces the concepts of the circle of life, food web, wrack line, and ecological balance. This serves as a baseline for understanding contexts later in **Chapter 2.4**.

First, we introduce the concept of **the circle of life**. In the field of biology, the circle of life or life cycle is the natural process that governs the lives of all living beings within four stages of development: birth, development, reproduction, and death. In nature, death is synonymous with life as when one cycle ends, another begins. The circle of life must continue because all species depend on each other for survival. Life cycles are continuous and when interfered with, can devastate an ecosystem. Human development and interference has destroyed various ecosystems such as forestland, coral reefs, wetlands, freshwater habitats, and beaches. When habitats are disturbed, so are the life forms that live within it including insects, animals, and plants. Therefore, the management of ecosystems is important to maintain the circle of life and food web system to maintain ecological balance.

Second, we introduce the concept of a **food web**. A food web is characterized by all the food chains in a single ecosystem. A food chain is one possible path that energy and nutrients may take moving through an ecosystem. Therefore, each living organism is a part of multiple food chains. For example, Piping Plovers eat marine worms, insects, crustaceans, and other small invertebrates but other shorebirds like terns also eat these food sources as well. Piping plovers are eaten by predators such as gulls, rats, and foxes. Within a food web, there are three trophic levels: producers (first), consumers (like Piping Plovers), and decomposers (last). Food webs are an important tool for illustrating the feeding relationships among species within a community, revealing species interactions and community structure, and understanding the dynamics of energy transfer in an ecosystem (Hui, 2012).

Next, we introduce what is called a **wrack line**. Wrack lines are a coastal feature where linear piles of marine debris and organic material (both natural and manmade) wash up on the beach from incoming waves and high tides. Wrack lines support an entire food web of beach critters including various insects, beetles, Piping Plovers, and other shorebirds. Other typical debris found in the high tide line are uprooted seagrasses, algae, seeds, mangrove leaves, sponges, soft corals, shells, egg cases, and worm tubes. The wrack line is an important ecosystem because it provides foot, habitat, and shelter for Piping Plovers and many other coastal species.

Finally, we introduce the concept of **ecological balance**. Ecological balance describes how ecosystems are organized in a state of dynamic equilibrium where species coexist in which genetic, species and ecosystem diversity remain relatively stable. Even if an ecosystem is balanced, gradual changes and disturbances still occur through natural succession that disrupts the balance. This includes loss of species in a food web ecosystem, introduction of invasive species, human-disturbances like development and climate change, natural disasters, and loss of species diversity. Therefore, for endangered species like Piping Plovers, it is important to maintain biodiversity and ecological balance of animals, plants, and microbial life in a food web to ensure the survival and existence of all living beings including humans (Verna, 2017).

After this informal introduction, we provide the formal definitions that are needed later in the report.

2.2 Newburyport Beach

Plum Island Beach in Newburyport, MA is the chosen summer destination of over 250,000 annual visitors who enjoy the beautiful barrier island as a place to relax and explore. While this public beach is frequently enjoyed by visitors, the upscale private properties on the island are becoming increasingly occupied by year-round residents (*Plum Island Beach*, 2022).

Located at the mouth of the Merrimack river, Plum Island Beach has faced erosion problems over the past several years; the dune system has experienced over 400 feet of erosion (GZA GeoEnvironmental, Inc., 2021). An ongoing project is underway to combat this erosion by placing dredged sand material as beach nourishment. The U.S. Army Corps of Engineers will dredge nearly 300,000 cubic yards of sand from the Merrimack River. The sand will be placed on the eroded dune system adjacent to Reservation Terrace in the Newburyport portion of Plum Island. The intention of this dredging project is to nourish and replenish the dunes, which will protect the coastal property and threatened bird habitats, including Piping Plovers and Least Terns.

2.3 Duxbury Beach Reservation

Duxbury Beach in Duxbury, MA is a 7.5-mile-long barrier beach extending from Marshfield to the Plymouth villages of Gurnet Point and Saquish. This beach is regarded as an accessible and family-friendly location. Mobility mats and ramp access are available at the park, as well as a beach wheelchair that can be requested. The Duxbury Beach Reservation, Inc. is a nonprofit corporation that owns approximately 4 miles of the beach. This organization leases most of the beach to the town of Duxbury for both resident and public use. Duxbury Beach requires parking permits for those who wish to drive onto the beach, in addition to the residents-only parking lot. Like Plum Island, Duxbury is seeing a shift from summer residents to year-round residents (NSRWA, 2022).

Duxbury Beach has also faced issues with erosion, including threats to the historic Powder Point Bridge. Like other barrier beaches, the sand at Duxbury Beach moves and changes

over time. Due to the sea walls of beaches to the north, Duxbury Beach is not currently receiving the natural nourishment of sand needed to maintain the dunes. An ongoing project at Duxbury Beach Reservation aims to create a natural approach to alleviate erosion by placing cobbles (small rocks and stones) around to protect the Powder Point bridge. Sand and cobbles will be used to build up the dunes, with a goal of preserving the beach, including its coastal bird habitats and vegetation (Stone Living Lab, 2022).

2.4 Conservation of Piping Plovers and Sand Dunes

In order to properly implement a passageway for beachgoers, it is crucial to understand and acknowledge the surrounding ecosystems, including sand dunes and endangered species, such as Piping Plovers. The design of the passageway must be considerate of these two vulnerable ecosystems.

2.4.1 Sand Dunes

A sand dune, by definition, is the accumulation of sand formed by wind, waves and eroding sandstone, with a structure that is constantly changing and growing due to natural patterns of the wind and the coastal tide (England, 2022). Coastal sand dunes are a highly dynamic, natural system which is composed of the shoreface (the open, sandy area between the dune and the high tide line), the beach itself.

Sand dunes are often referred to as a “natural fence” because of their strong natural properties to protect against coastal flooding and erosion. During events of high tidal waves or destructive storms, sand dunes are able to adapt naturally to wind and water patterns in order to disperse energy across the coastline and create a protective front to communities and property that lie directly behind them (Heurtefeux, et. al., 2021).

In addition to natural protection against rising sea levels and flooding, sand dunes form an excellent buffer against erosion (*Importance*, 2022). When a dune is healthy and free of any foreign threats, it is able to function to its highest ability to preserve and move sand naturally through the dune and back on to the beach, doing its best to protect against coastal erosion; where the rising tide will continuously over time take sand from the beach deeper offshore under the sea level (Jesse, 2008).

2.4.2 Historical Evolution of Piping Plovers

The Piping Plover (Charadrius melodus) is a small sand-colored, sparrow sized migratory shorebird that nests and feeds on sandy beaches, tidal flats, and open sandy areas near the water in North America (U.S. Fish, 2022). They weigh around 1.5-2.25 ounces, measure at 5.5-7 inches long, and have a wingspan of 15 inches. Their population consists of mainly two different subspecies of plovers: C.m. circumcinctus lives along the shorelines of the Great Lakes and

along the rivers and lakes in the Northern Great Plains while the other, C.m. melodus lives along the Atlantic Coast. This report focuses on the latter.

Piping Plovers were common along the Atlantic Coast during the 19th century, but almost became extinct due to excessive hunting for the millinery trade (designing of women's hats). However, the Migratory Bird Treaty Act was passed in 1918 by Congress and signed by President Woodrow Wilson, which prohibited the take (killing, capturing, selling, trading, and transport) of protected migratory bird species without prior authorization by the Department of Interior U.S. Fish and Wildlife Service (U.S. Fish, 2020). The Piping Plover population increased in the 20th century during the 1940s, but since then, their population has continued to decline. The Endangered Species Act of 1973 was passed but only until 1986 did they become protected (Endangered, 2020). The inland populations of plovers were listed as endangered, while the coastal population was listed as threatened. This migratory bird species is also protected as a Threatened Species by the Massachusetts and Federal Endangered Species Lists. However, with all this in place, Piping Plovers began to decline in 1950 after World War II due to pressure from development, beach stabilization programs, increased recreation, and human-caused ecosystem changes. In 2006, the Piping Plover made the Audubon Society's "top 10 most endangered species'" list with all three populations containing a total of fewer than 8,500 breeding adults (Maddock, n.d.). As of 2022, there are only 74 nesting pairs, yet conservationists state that there should be 200-300 nesting pairs to completely restore the plover population. Piping Plovers are listed on the IUCN (International Union for Conservation of Nature) Red List (**Figure 1 & 2**) as "Near Threatened" but even with some populations increasing, their threat to decline is too great.

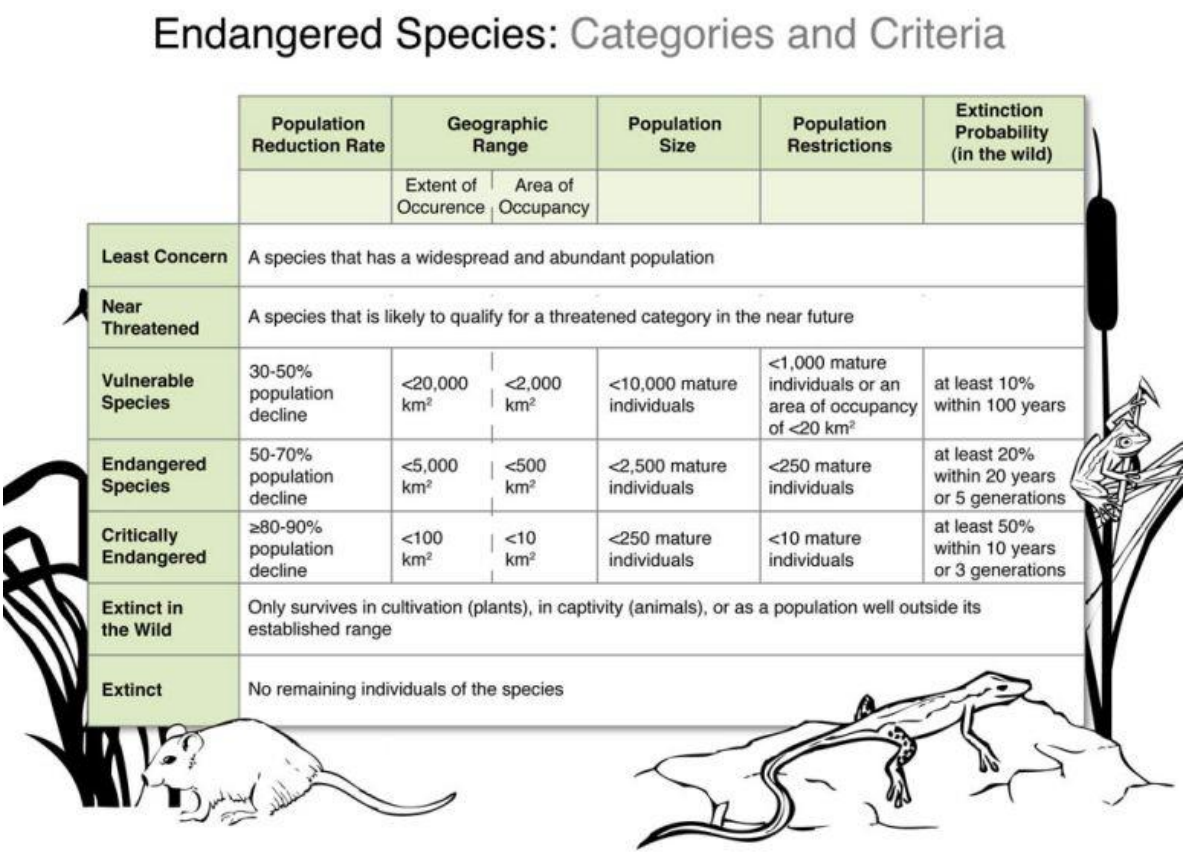


Figure 1. Seven of the nine endangered species categories on the IUCN Red List. Piping Plovers are listed under the "Vulnerable" and "Endangered" Species Category (Crooks, n.d).

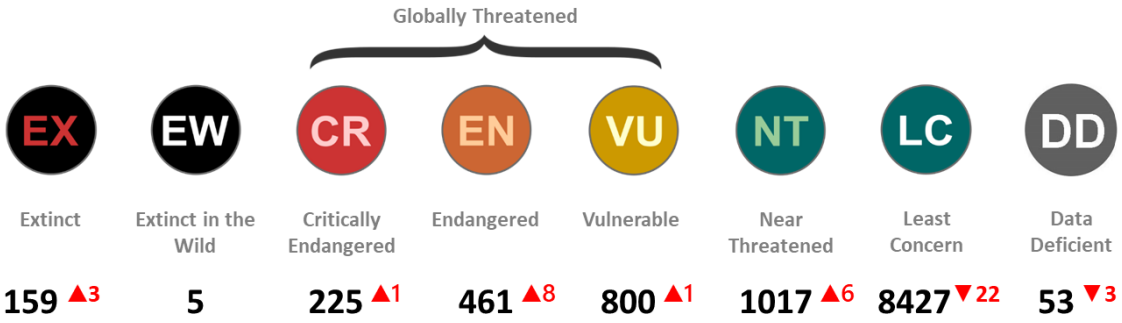


Figure 2. The nine categories' species are categorized under on the IUCN Red List. The new Conservation Status some scientists now use to evaluate species include "Data Deficient" and "Not Evaluated". The black numbers represent the number of bird species in each category and the numbers in red indicate the net change since the previous year's assessment (BirdLife, 2020).

2.4.3 Piping Plovers Wildlife-Habitat Relationship

Wild animals require four basic habitat components-food, water, cover, and space (home range). The amount of distribution of these will influence the types of wildlife that can survive in an area (Brittingham & DeLong, 1997). As the quantity, type, and distribution of habitat components change, so do the types of wildlife species found within the habitat. For an endangered and threatened species like Piping Plovers, wildlife management is crucial to manipulate components of their habitat to ensure their survival. This may include altering the vegetation in the area to provide proper food and cover.

Piping Plovers require cover for many life functions including nesting, escaping from predators, seeking shelter from elements, and resting (Maddock, n.d.). They are typically found along the Atlantic Coast and Great Lakes on tidal flats and beaches, sandbars along major rivers on northern Great Plains, and gravel or sand flats next to alkali lakes in the summer. In the winter, Piping Plovers migrate to the Gulf of Mexico and southern Atlantic Coast of the United States and Caribbean. They breed in sand dune ecosystems and arrive in March to nest between late April to June.

Piping Plovers nest on open ground, some distance away from water, often with large rocks or clumps of grass nearby with no direct shelter or shade. They build their nests in a narrow area of land between the high tide line and the foot of the coastal dunes, vegetated dunes, and eroded areas behind dunes. They nest in shallow scrapes in the sand, sometimes lined with tiny shells and pebbles (**Figure 3a & 3b**).

(a) (b)

Figure 3. Examples of Piping Plover nests. (a) shows a nest in a shallow scrape of sand with vegetation (Bellman, 2022) while (b) shows a nest in a shallow scrape of sand surrounded by rocks, shells, and vegetation (Seccombe, 2008).

They may nest close to colonies of terns which is another endangered seabird species that also live by the sea, rivers, and wetlands that are vulnerable to climate change and destruction of habitat. Plovers prefer to nest near terns because terns are a protected bird species and therefore provide protection over Plover hatchlings. Gulls, rats, feral cats, foxes, and racoons are all predators to Plovers that feed on their adults, chicks, and eggs. Although Plovers' nests camouflage into the sandy environment due to their color and nesting location, predators still find their nests. One may assume that the Plover population decline is due to the principle called the circle of life and the food web within the sand dune ecosystem, but the biggest threat to Piping Plovers are humans.

2.4.4 Human Disturbance Affects Piping Plovers

Piping Plovers are particularly vulnerable to off-road vehicles, encroaching human development/disturbance, and human-induced climate change that causes erosion. Off-road vehicles uproot Plover habitat, by directly killing adult birds, eggs, and destroying nests. Human development and activities, along with urbanization contribute to the decline of the Piping Plover population. High human traffic levels increase the likelihood that plover eggs and foraging will be disturbed. Foraging plovers interrupted by humans stop foraging, move away from the area, then wait until the disturbance no longer exists (Webber, Heath, & Fischer, 2013). In doing so, they spend too long avoiding the disturbance and not enough time hunting for food. Their food is found in the wrack line which coincidentally is where humans walk along the beach. Plovers feed on insects like beetles, water boatmen, shore flies, midges, marine worms and invertebrates, and crustaceans but humans also leave food scraps and litter for Plovers to eat. Plastic pollution and climate change are an exacerbated result of human development and because sea levels are rising, more frequent and intense rain events and storms occur, causing inundation and increased erosion. Climate change also destroys Plover habitat, nests, and migration patterns due to these extreme temperatures and sea level rising. Climate change-induced sea level rise, especially where natural barrier beach dynamics are impeded, is seen as an emerging new threat to Piping Plover populations (Sassi, 2015).

There are only 4,000 breeding pairs of Piping Plovers left worldwide and as humans take over more beach areas for development and recreational purposes, Piping Plovers find themselves displaced or forced to share the beach (Audubon, 2021). In 2018, a compelling study was performed by researchers in a range of environmental organizations, including the Department of Fish & Wildlife Conservation, the U.S. Fish & Wildlife Service, and the Audubon Society to determine the impacts of human disruption on Piping Plovers, when humans leave breeding grounds alone. This study unearthed that birds from beaches with more human disturbance weighed about 7% less than birds on more sheltered beaches. The more human disturbances there were, the more birds died (Gibson et al., 2018). While it may have seemed logical that the birds that were disturbed by humans would move to a nearby, less disturbed beach, researchers found that this rarely happened. Birds were mostly loyal to their particular beaches, even if the stress of it would kill them and their time and energy was spent waiting for the disturbance to leave.

2.4.5 Piping Plover Importance and Role in the Ecosystem

Piping Plovers are indicator species that allow scientists to get a glimpse of the condition of the ecosystem they live in for the health of beaches and dunes because they require a specific habitat to thrive (Vinelli, 2000). Their economic and ecosystem importance and role is attributable to their breeding pairs and beach cleaning they provide. The Plovers' economic benefit stems from their control over their predators and prey populations of insects, beetles, and small crustaceans on beaches, dunes, and in the tidal wrack, while the abundance of breeding pairs in an ecosystem reflect the availability of beach nesting habitat and management efforts to protect them from human disturbance, storm tides, and predators. If Piping Plovers went extinct, their prey population would increase, while their predators would decline, as one of their main food sources would be unavailable. If one species in the food web ceases to exist, one or more members in the rest of the chain may too. The circle of life in the sand dune ecosystem would be imbalanced. Ecological balance is important as it leads to the continuous existence of organisms and ensures no particular species is exploited or overused.

2.5 Accessibility on Beaches

In defining accessibility on beaches, it is necessary that all forms of accessibility are accounted for. This includes people, those who are disabled, those in lower economic status, and local wildlife among all other beach visitors and inhabitants.

2.5.1 Ramps

In effort to make beaches accessible in the physical sense, platforms and pathways can be focused on to ensure this physical travel. Having clearly constructed and visible passageways to conduct travel to the beach are imperative to allowing easy and inviting methods of visitors to the shore. Ramps are a commonly used infrastructure to incorporate into beach designs. They can be made out of a variety of materials. Much design consideration is necessary of ramps to keep them fit for their location of implementation.

As far as their limitations, there are several American with Disabilities Act (ADA) guidelines that the designs must follow in order to stay in compliance with safety precautions. One such regulation is the steepness of the rampway. A slope that is too large can be dangerous to those in wheelchairs and those with other walking disabilities (Darlington, 2016). Other ADA guidelines dictate the procedure of construction and placement in relation to sand dunes. Sand dunes protect the beach ecosystem and issues related to erosion and flooding. In order to keep them intact and able to serve their intended purpose, ramps must not be built to disrupt their structure, meaning to be built away from the dues above them.

Other aspects of the ecosystem that ramps tend to harm are that of vegetation and the natural movement of the beach foundation and nature. Vegetation often works with the beach landscape to prevent flooding and mass erosion. Absorbing qualities of the plants keep such

environmental processes at a halt and slow their destructive properties. In clearing area to construct such ramps, much vegetation needs to be removed or altered, removing the positive impact they hold on to the beach landscape (Accessible Beaches). The beach landscape also naturally shifts due to winds and tides. Certain ramp infrastructure can be detrimental to allowing this movement of sand by blocking sections from natural rearrangement and throwing off the natural landscape. A permanent structure such as a ramp also cannot easily be manipulated to fit these changing beach landscapes.

Specific ADA requirements also cater to the population of disabled beach users. In such requirements, the slope of the ramp must not exceed a 1:12 ratio and must be more than 36 inches in width depending on the state regulations of the area (BraunAbility, 2021). The edges of the ramps must also have established protected edges to maintain an aspect of safety and precaution to falling off. The entry and exit of the ramps should also be much wider to allow for safe maneuverability as well as be designed with landings that are at least 60 inches in length. Rest platforms are also necessary in the design every 30 ft so that users can have space to take breaks and avoid fatigue.

Rails are also an important component to the ramp design. To remain in compliance with the regulations set through the National Council on Disability, rails must be equipped on both sides with an 11.5-inch space between the handrail and the attached wall (BraunAbility, 2021). The rail must also be constructed with no gaps and be a strict 34-38 inches above the ramp floor.

In regard to expense, the initial construction cost varies depending on material and size to around $25,000 to $100,000 (Accessible Beaches). Many smaller and not well funded beaches do not have that extent of money to put into such a project, but the even steeper issues come with the upkeep of ramps. Not only is the fixing of the ramps costly, but also hard to manage and track. A lot of the damage is caused by storms as well as tides and winds. With all of these environmental effects occurring very regularly, it is difficult to track the direct damage on the infrastructure and also figuring out how to implement the design fixes.

2.5.2 Beach Mats

The less expensive option to the more permanent infrastructures proposed are beach mats. These mats are present at many Massachusetts beaches, in compliance with ADA regulations, and allow those with disabilities to remain in their own wheelchair, even if it is not designated for beach navigation. The sand and mat combination creates a firm texture that acts well with wheels from the wheelchair to facilitate movement (Mobility, 2022). Many of these mats are made out of rubber and are non-slip as well and are more consistently priced, averaging at about $10,000 for each passageway (Miller, 2022).

Limitations to mat implementation deal with the length to not spill into any natural habitats of animal inhabitants. They are also lightweight and have a higher likelihood of moving from wind and tides and being displaced. Since they are not elevated, they also are more

vulnerable to being buried by sand and offer no protection to any sand dunes that the design would navigate through.

In order for the mats to also be as accessible to the public as possible, it is necessary for them to be directly connected to solid unsanded areas. If the mat is not connected to solid ground, the implications of wheelchair movement are prevented as the vehicle cannot navigate to the passageway easily.

2.5.3 Wheelchairs

In terms of catering to the population living with various disabilities, beach wheelchairs are commonplace on beaches, as there are designs equipped specifically to handle sand and rigorous terrain. Without these chairs, a large number of people are not able to access this integral summer activity. The process of obtaining the use of these chairs for a beach day currently sits as a very complicated set up. Oftentimes there is a limited supply of chairs and use of such are charged hourly. Other beaches do not have chairs to offer, so outside individuals and companies need to be reached out to. Issues relating to distance, limited supply and expense all come into play with obtaining chairs from outside sources.

The design of these chairs will work and roll through sand as well as be taken directly into the water. With these chairs, mats and ramps alike are not dependent on the transportation of these individuals. There are issues in the design of some of these chairs as there are many different designs on the market today. Such functionality issues arise when their ability to maneuver through the sand and rough terrain is not as fluent as expressed. Most of these chairs are extremely difficult to get onto the beach and for people to get into. Getting into these wheelchairs are not always independently done, as they are too elevated and do not contain necessary design aspects to allow for easy self-navigation into. There are many different designs of chairs, and some are better equipped to maneuver in sand and get people into independently

2.5.4 Transportation System

Parking and transportation to beaches is also an imperative foundation to navigating the seasonal visitors to beaches. In Massachusetts, much of the beaches are under private access and require strict parking permits for those not living within walking distance. Many beaches have fallen under the issue of not having enough parking passes and parking lot spaces for the population who wants to participate in the beach activities. Attacking the issues related to the ability to secure a position near the beach to travel from are important to distant travelers and lower income families that cannot afford to live in the area or purchase passes. Solutions to these traveling issues are constructing more parking areas or constituting an effective bus or organized beach transportation system.

2.6 Best Management Practices for Beach Construction

In order to properly maintain a beach to the best standards in terms of accessibility, conservation, and eco-friendliness, there are lots of procedures and tips that need to be accounted for. When constructing on a beach, it is vitally important to protect the natural ecosystems that surround the construction area, including sand dunes and species that may habitat within (MA DCR, 2015). Sand dunes are the buffer to storm surges and flooding, providing protection to coastal property and preventing erosion. These dunes also often act as the home to beach-bound species, making them extremely important to protect during construction and maintenance.

2.6.1 Design Tips for Beach Construction

The most important consideration when constructing around a natural ecosystem, other than the stability and longevity of the structure, is minimizing the impact to its surroundings. The Massachusetts Office of Coastal Zone Management (CZM) has standards for the basics of building beach access structures in order to limit and prevent potential harm to natural surroundings during the design and construction process (MA Office of Coastal Zone Management, 2021).

The biggest threat to vulnerable sand dunes and beach ecosystems is humans. Limiting the structure to only the necessary size to achieve the goal of aiding beachgoers over sand dunes and onto the beach is recommended. Overly large structures will limit the growth of beach grass, which is vital to maintaining the proper functions of a natural dune system (England, 2021). Structures should be no wider than 4’ (48”) and no longer than necessary to access the beach (England, 2021). Elevating structures at least 2’ (24”) above grade of the shore will allow for the sand, grass, and sediments to resume natural movement patterns underneath the structure, while also protecting them from being trampled by human foot traffic (MA Office of Coastal Zone Management, 2022). Beach ecosystems thrive off of sunlight, which is an important consideration in design. Spacing planks 1” apart to allow for sunlight to pass through, while still not posing a danger to users, is suggested.

Considering length and time of construction contributes to the vulnerability of the ecosystems. Construction should be conducted during the fall or early spring months, when beachgoers are less likely to be on the premises, but before or after peak winter storm season has passed. Constructing in the winter can expose vulnerable areas, including bird nests, dunes, and coastal property, to the intense storms Massachusetts beaches face during the winter months. Additionally, materials used should be resistant to rot and deterioration due to the varying climate Massachusetts faces throughout the year. These materials should be able to withstand snowstorms, sand erosion, and salt water.

Wind patterns play a big role in determining the direction of the access way. Sand dunes rely on natural wind tunnels to provide the wind energy required to transport and move sand, which enables the natural movement and transformation of the dune to stay strong as a barrier against erosion and flooding (England, 2021). Wave tunnels, powered by and in the same direction as the wind, are vital in replenishing the dunes with fresh sand and allowing their

natural movement. The access way should be angled away from the dominant wind direction in order to avoid the impact to natural wind and wave tunnels (**Figure 4**).

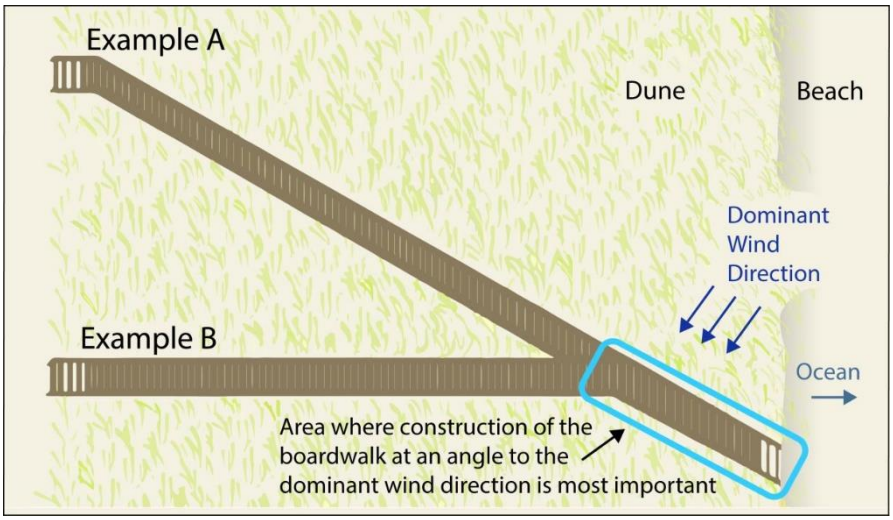


Figure 4. Boardwalks correctly constructed at an angle to dominant wind direction (MA Office of Coastal Zone Management, 2022).

2.6.2 Permitting Information

Any construction, specifically construction performed on a beach, requires a lot of permitting in order to proceed. An ocean beach is protected by the Massachusetts Wetland Protection Act (WPA), which protects waterfront areas from destruction or alteration in the state of Massachusetts (MA Department of Environmental Protection, 2022). WPA allows pedestrian walkways on dunes so long as it minimizes disturbances and promotes the ability of the dunes to move and shift naturally. Due to the structure likely being built in close proximity to nesting habitats of endangered species, any design will likely warrant review by the Natural Heritage and Endangered Species Program (NHESP) (Division of Fisheries and Wildlife, 2022). NHESP will ensure that the nesting of the endangered species, including piping plovers, is not impacted by new construction.

Other permits to consider that may vary per location include the state's Chapter 91: Public Waterfront Act and Waterways Regulations (310 CMR 9.00), and federal Rivers and Harbors Act and Program Regulation (MA Office of Coastal Zone Management, 2022). Additional important permits to consider surrounding construction through dunes include Massachusetts State Building Code, and local Conservation Commission and Massachusetts Department of Environmental Protection's (MassDEP) Wetlands and Waterways program. A lot of permitting through various local, state, and federal agencies are required in order to construct on the beach, specifically through dunes.

Chapter 3

Methodology

The goal of this project is to design an accessibility passageway for beachgoers on Plum Island and Duxbury Beach that protects and preserves its surrounding ecosystems, while considering sand dunes and piping plovers. Our objectives to achieve this goal are:

- Become familiar with Best Management Practices (BMPs)
- Identify sites with interest in our design
- Collect data about interested sites
- Analyze data collected
- Research materials to use for the accessway
- Evaluate of preliminary design
- Explore the feasibility of implementing the design to various beaches in Massachusetts
- Create a Best Management Practices guide concerning implementation of the passageway

The expected timeline to complete these objectives is depicted in **Figure 5**.

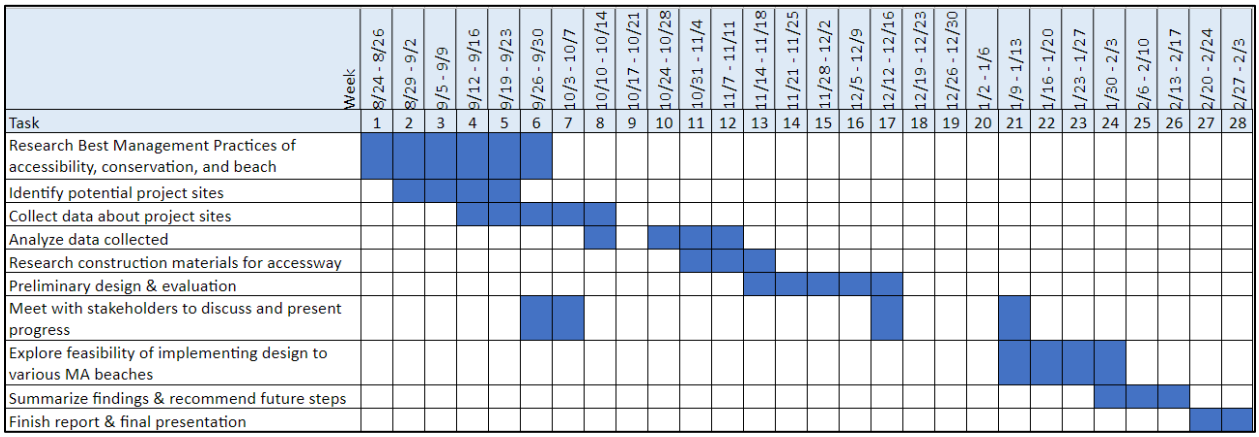


Figure 5. The Gantt chart depicts the expected timeline of our objectives.

3.1 Become Familiar with Best Management Practices (BMPs)

In-depth literature reviews will reveal the Best Management Practices in terms of accessibility, conservation of piping plovers, and conducting construction on a beach (see background section 2.6). Literature reviews on Massachusetts beaches that have implemented accessibility passageways through dunes and understanding the successes and failures of these past projects will be evaluated and used to determine the Best Management Practices for creating our design. Compiling information found will aid us in understanding the best way to design and implement this passageway to both Plum Island and Duxbury Beach Reservation.

3.2 Identify sites with interest in our design

In the initial outreach phase, our team identified two (2) sites that were interested in our design (see background sections 2.2 and 2.3). Newburyport's Plum Island and Duxbury Beach Reservation both expressed interest in our project and efforts towards designing an accessible beach accessway.

3.3 Collect data about interested sites

A lot of data will need to be collected in order to properly design an accessway and give recommendations for implementation. Collection of specifications for each interested site will take place so that the design and recommendations can be tailored to both Plum Island and Duxbury beach individually. These data include normal wind direction, grade of the beach, GIS maps of existing and proposed areas, locations and projected movement of piping plover nests, budget, allotted timeline, and state of the beach. Getting more knowledge of both locations of possible implementation will include site visits to determine where a passageway would start/end, and to get a general sense of the working site.

3.4 Research materials to use for the passageway

Literature review on case studies of accessible beach passageways as well as conversations with representatives from Massachusetts beaches will reveal the proper criteria to look for when examining materials for an accessible passageway. It is understood that any material used will need to be durable, weather-resistant, waterproof, and non-harmful to the surrounding environment (see background section 2.6.1), however expanding our outreach to learn more about materials to use will aid us in the design.

3.5 Analyze data collected

Data collected about interested sites will be used in designing and implementing the passageway. For both Plum Island and Duxbury Beach, we will use site visits and information from conversations with representatives to determine where the passageway would begin and end, the slope on which the passageway should be designed to accommodate, and the mobility of the passageway with the seasons. Using specifications from beaches, analyzing further information found through literature review on BMPs and materials (see methods 3.1 and 3.4, respectively), we will be able to begin the design of an accessible passageway.

3.6 Evaluation of Preliminary Design

After preliminary design of our passageway structure, we will seek a professional opinion to review and check the principal engineering components, including structural integrity and durability. It is our hope that we can speak with Professional Engineers from both Newburyport and Duxbury throughout the whole process so that they will be able to give guidance on the development and implementation of the design.

3.7 Exploring feasibility of implementing design to various beaches in Massachusetts

The goal of our project is to create a design of an accessible beach passageway that can be implemented to various Massachusetts beaches according to their own specifications. Once our design is finalized, feasibility, constructability, and manufacturability will be examined for Plum Island and Duxbury Beach for implementation of the design.

3.7.1 Newburyport Plum Island

Factors to be considered for implementation to Newburyport include cost and budget limitations, access to materials, availability of workers, along with the site-specific data collected and analyzed (see Methods section 3.3 and 3.4).

The effectiveness of the design is something to be considered as well. We will conduct a Risk Analysis on the implementation to determine what possible impositions may arise. Additionally, we will work with Julia Godtfredsen, Conversation Administrator for the Town of Newburyport, along with any other related representatives to determine if it is appropriate to conduct a community survey surrounding the abutter's thoughts and feelings on the usefulness and impact of a new passageway on Plum Island.

3.7.2 Duxbury Beach Reservation

Factors to be considered for implementation to Duxbury Beach Reservation include cost and budget limitations, access to materials, availability of workers, along with the site-specific data collected and analyzed (see Methods section 3.3 and 3.4).

The effectiveness of the design is something to be considered as well. We will conduct a Risk Analysis on the implementation to determine what possible impositions may arise. Additionally, we will work with Sue MacCallum, Outreach Coordinator for Duxbury Beach Reservation, along with any other related representatives to determine if it is appropriate to conduct a community survey surrounding the abutter's thoughts and feelings on the usefulness and impact of a new passageway on Duxbury Beach Reservation.

3.8 Summarize findings of design and give recommendations

Using findings concerning Best Management Practices (BMPs), data collection (see Methods sections 3.3), along with the knowledge gained through implementing our passageway design to two different beaches on various coasts of Massachusetts, we will outline our findings and educated recommendations for implementing our design to a Massachusetts beach. We will provide the outcomes of our research and what we learned about the best practices when designing and implementing a beach passageway through sand dunes, while being cognizant of the surrounding ecosystems.

Additionally, we will create a checklist displaying the specifications included and what criteria from both Newburyport and Duxbury Beach were met or still lacking. This will help aid these sites understand what aspects are within and how they may be able to use it on their beach ecosystem.

Annotations

Accessible beaches. Mass.gov. (n.d.). https://www.mass.gov/service-details/accessible-beaches.

Audubon Connecticut. (2021). *8 Ways to Help Piping Plovers*. Conservation. https://ct.audubon.org/news/8-ways-help-piping-plovers.

Bellman, H. (2022). *Piping Plover program*. DNREC Alpha. https://dnrec.alpha.delaware.gov/fish-wildlife/conservation/piping-plovers/.

BirdLife International. (2020). *State of the World's Birds: 2020 Annual update*. BirdLife Data Zone. http://datazone.birdlife.org/2020-annual-update.

BraunAbility. (2021). *What are the Ada Ramp Requirements*. BraunAbility. https://www.braunability.com/us/en/commercial/white-papers/.

Brittingham, M. C., & DeLong, C. A. (1997). *Wildlife-Habitat Relationships*. Penn State Extension. https://extension.psu.edu/wildlife-habitat-relationships.

Crooks, M. (n.d.). *Endangered Species*. National Geographic Society. https://education.nationalgeographic.org/resource/endangered-species.

Darlington, A. (2016, November 2). *Making beaches accessible to disable an uphill battle for authorities*. Post and Courier. https://www.postandcourier.com/archives/.

Division of Fisheries and Wildlife. (2022). *Mass Wildlife's Natural Heritage & Endangered Species Program.* Mass.gov. https://www.mass.gov/orgs/masswildlifes-natural-heritage-endangered-species-program.

Endangered Species Coalition. (2020). *Piping Plover Birds*. Endangered Species Coalition. https://www.endangered.org/animals/piping-plover/.

England, R. (2021). *Why are sand dunes important?* OneHome. https://onehome.org.uk/the-bigger-picture/424-why-are-sand-dunes-important.

Gibson, D., Chaplin, M. K., Hunt, K. L., Friedrich, M. J., Weithman, C. E., Addison, L. M.,Cavalieri, V., Coleman, S., Cuthbert, F. J., Fraser, J. D., Golder, W., Hoffman, D., Karpanty, S. M., Van Zoeren, A., & Catlin, D. H. (2018). Impacts of anthropogenic disturbance on body condition, survival, and site fidelity of nonbreeding Piping Plovers. *The Condor, 120*(3), 566–580. https://doi.org/10.1650/condor-17-148.1.

GZA GeoEnvironmental, Inc. (2021). Notice of Intent Application: NFS Permitting of Dredge Spoil Beneficial Use. Plum Island Reservation, Newburyport, Massachusetts.

Heurtefeux, H., Milor, M., Bichot, A., & Grosset, S. (2021, October 8). *Dynamics, threats and management of dunes.* Marine Species Wiki. https://www.marinespecies.org/introduced/wiki/Dynamics,_threats_and_management_of_dunes/.

Hui , D. (2012). *Food Web: Concept and Applications*. The Nature Education Knowledge Project. https://www.nature.com/scitable/knowledge/library/food-web-concept-and-applications.

Jesse, J. (2008, December 17). *What Causes Beach Erosion?* Scientific American. https://www.scientificamerican.com/article/what-causes-beach-erosion/.

Maddock, S. (n.d.). *Natural History* . Center for Biological Diversity. https://www.biologicaldiversity.org/species/birds/piping_plover/natural_history.html.

Mobility Mats - Tampa Bay, Florida. Help Us Gather - HUG. (2022, September 9). https://helpusgather.org/mobilitymats/.

Massachusetts Department of Conservation and Recreation (DCR). (2015, March). *Beach Maintenance and Operations.* Mass DCR Office of Regional Planning. https://www.mass.gov/doc/beach-maintenance/download.

Massachusetts Department of Environmental Protection. (2022). *310 CMR 10.00: Wetland Protection Act.* Mass.gov. https://www.mass.gov/regulations/310-CMR-1000-wetlands-protection-act-regulations.

Massachusetts Office of Coastal Zone Management. (2022). *CZ-Tip - Basics of Building Beach Access Structures that Protect Dunes and Banks.* Mass.gov. https://www.mass.gov/service-details/cz-tip-basics-of-building-beach-access-structures-that-protect-dunes-and-banks.

Miller, D. (2022). *Mobility mats are coming to Clearwater Beach. this resident hopes more beaches will follow suit*. WUSF Public Media. https://wusfnews.wusf.usf.edu/health-news-florida/.

NSRWA. (2022, July 23). *Duxbury Beach Reservation*. North and South Rivers Watershed Association. https://www.nsrwa.org/listing/duxbury-beach-reservation/.

Patten, P. V. (2016, July 21). *Protecting dunes: Connecticut beaches and Dunes: A hazard guide for coastal property owners*. Connecticut Beaches and Dunes A Hazard Guide for Coastal Property Owners. https://beachduneguide.uconn.edu/protecting-dunes/#:~:text=Sand%20dunes%20provide%20natural%20coastal,supplying%20sand%20to%20eroded%20beaches

Plum Island Beach. (2022). Newburyport.com. https://www.newburyport.com/plum-island-beach/.

Sassi, J. (2015). *Conservation of Piping Plovers at Napatree Point: A Case Study in Collaboration, Science, and Education*. Conservation in a Changing Climate. https://climatechange.lta.org/whlc-piping-plovers/.

Sea level rise. Mass.gov. (n.d.). https://www.mass.gov/info-details/sea-level-rise.

Seccombe, M. (2008). *Against odds, Piping Plovers rebound*. The Vineyard Gazette - Martha's Vineyard News. https://vineyardgazette.com/news/2008/06/05/against-odds-piping-plovers-rebound.

Stone Living Lab. (2022, January 21). The Duxbury Beach Reservation creates nature-based approaches to address erosion. Stone Living Lab. https://stonelivinglab.org/news-article/duxburyerosion/.

The importance of sand dunes to the coastline. (2022). SurferToday. https://www.surfertoday.com/environment/.

Toimil, A., Camus, P., Losada, I. J., Cozannet, G. L., Nicholls, R. J., Idier, D., & Maspataud, A. (2020, January 30). *Climate change-driven coastal erosion modelling in temperate sandy beaches: Methods and uncertainty treatment*. Earth-Science Reviews. https://www.sciencedirect.com/science/article/pii/S0012825219303861#s0015.

U.S. Fish & Wildlife Service. (2020). *Migratory bird treaty act of 1918: U.S. Fish & Wildlife Service*. FWS.gov. https://www.fws.gov/law/migratory-bird-treaty-act-1918.

U.S. Fish & Wildlife Service. (2022). *Piping Plover*. FWS.gov., https://www.fws.gov/species/piping-plover-charadrius-melodus.

Verna, A. K. (2017). *Necessity of Ecological Balance for Widespread Biodiversity*, *4*(2), 158–159. https://doi.org/https://doi.org/10.21088/ijb2394.1391.4217.15

Vinelli, R. (2000). *Charadrius Melodus (Piping Plover)*. Animal Diversity Web. https://animaldiversity.org/accounts/Charadrius_melodus.

Webber, A. F., Heath, J. A., & Fischer, R. A. (2013). Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during the breeding season. *Ecology and Evolution*, *3*(4), 853–863. https://doi.org/10.1002/ece3.511.

Appendix B: Universal Access Meeting Minutes

BEACH ACCESSIBILITY AND CONSERVATION- WPI/DCR UNIVERSAL ACCESS

Project Goal: To provide recommendations for accessible passageways for all beachgoers that considers the environmental constraints and surrounding ecosystems, including sand dune and piping plover habitats, for various Massachusetts beaches

MEETING INFORMATION

Date & Time: 02/03/2023 ***Location:*** Zoom

Attendees: Nadiya Chalak (WPI), Catie Coumounduros (WPI), Madison Garrity (WPI), Colette Webster (WPI), Rachael Lee (DCR), Tom McCarthy (DCR)

QUESTIONS SENT TO MS. LEE AND MR. MCCARTHY PRIOR TO MEETING

- What efforts has DCR made in terms of providing accessibility to Massachusetts beaches?
- What are the greatest challenges in implementing/constructing accessible passageways to beaches that previously hadn't been accessible?
- What methods of implementation or materials have you found to be the most successful in your experience?
- How can we incorporate the accessibility guidelines into our design?
    - "Bump Outs" on pathways as rest platforms, Railings, etc.
- How has implementing accessible passageways affected the surrounding habitats (sand dunes, piping plovers, other specific) in your experience?
- How have you seen erosion and rising tides affect the longevity of structures?
    - Have you ever worked with moveable structures (i.e. Mobi-mats, moveable parts of wood structures for off-season, adjustable height of boardwalks, etc.)?

MEETING NOTES

- Universal Access started in 1995 with a mission goal to exceed minimum standards while providing access to state parks for everyone regardless of their ability
    - Looked at all of the recreation activities people enjoy
    - Climate change and how plans are going to work with that
    - Making people with all abilities comfortable in the outdoors
    - Adaptive programs for folks with disabilities
    - Looking more at design and physical accessibility
    - Dive into how people use the spaces and how to accommodate for accessibility

Duxbury Beach Reservation Design

- Handrails and guardrails will be required on entirety of design

    - Federal standards don't require them
    - State standards do
    - Good to include hand/guardrails to be conservative and safe
- Handrail spacing: 48 inches minimum
- MA follows ABA (Architectural Barriers Act) Standards for Accessibility
    - On a ramp you need handrails and min clearance is 48 inches
    - Would need guardrails if the height goes up to 16 feet
        - If you need guardrails → generally good practice to put handrails on as well
        - Handrail graspable surface for navigation
    - Guardrail is safety aspect
- Past projects have not been completely over dunes - this project is different as it is scaling the dune
    - More visible design to the public, they wil know where to access it
    - Less cuts into the dune since it scales over
- Wooden ramps include a lot of overlapping regulations
    - 60 inches for width on full route
    - Ramp requirements minimum of 5 feet wide (handrails 48 inches apart)
    - Ideally want enough width that someone could turn around, or just able to pass
        - 36 inches is ADA minimum for ramp width, generally good to give 48-60 inches of length to allow folks more space
- Built structures are very expensive (lots of material) and never know what's happening around them
    - Temporary access points versus large building projects

Newburyport Plum Island Design

- Jersey block could be a good solution, maintenance and operation solution
    - Ramp requires much upkeep and maintenance
    - Structure of a ramp in Newburyport could be aesthetically unpleasing, hard to take down in the off-season
    - Moveable barrier for sea water at high elevation, have something right there on the site that could be moved by 1-2 people in the event of a storm, potential flood, or just to avoid erosion from sand to road
- General pros and cons of Mobi-mat
    - Generally 2 person job to move them in and out
    - Good experience, come with challenges
    - Need staffing to move and upkeep it (usually limited)
    - Keeping the sand off the Mobi-mat can be a labor-intensive job, sand build up can make the mat a non-accessible passageway over time if not maintained
    - Chair can push mat ahead of person
    - Makes sand passageways accessible
    - Flexibility is benefit for storms, end of season, storage
    - With rising tides, permanent structures are getting washed away whereas Mobi-mats can be moved and shifted with the changing tide
    - Mats tend to need more maintenance

    - Tends to fray over time, may need to ne replaced, usually last at least 10 years depending on location
    - Storage wise: needs to be stored laying down and not standing on ends (can get really worn when placed for long time on its ends)
        - Need adequate storage space (fully covered) for mat in off-season
    - Shifting winds and sand can mean beach mat will have to get weekly maintenance
        - Think about operations, capacity, desire, staff
        - Having dunes around mat is helpful, dunes will protect mat from a lot of sand build up (good for case of Newburyport)
        - Direction of wind (wave and sand shifting patterns) matter in orientation that the mat gets laid down → if directly perpendicular to this direction more maintenance will be required to clear sand
- Built-up structures have maintenance to keep sand blowing in
    - Guardrails and handrails can catch it, with no hand/guardrails on Mobi-mat, more susceptible to sand blowing

Additional Information

- Longevity of moveable boardwalks
    - Not big structures but just slabs of wood
    - Seem to hold up pretty well
    - Removable structures:
        - Plastic (AccessDeck) sections of decking that you can link up and move around with the seasons/in event of a storm
- AccessMat: wire mesh that's coded, doesn't have fraying problem and holds up a little better
    - Heavier so more maintenance
    - Generally more expensive
- Plastic and recycling: brand mats are made out of recycled plastic
    - When mats are at the end of their life they just turn into waste, can't be recycled again
- Staffing is the biggest issue, making sure mat is mesh to most accessible surface
- Access to beaches is very hard to meet requirements given changing environment to beaches, high tide level changes
- When designing for beach access:
    - Document why you won't put in fixed access points
    - Compromising standards makes it cheaper but can hurt people
    - Finding ways to mitigate maintenance for access routes, coming up with maintenance or management plan
- Maintenance with any structure
    - Always something to consider
    - Having a management plan on how to maintain
    - Sand is really challenging in terms of accessibility
    - As soon as sand gets on it becomes a challenge and requires staffing
- Visitor experience:
    - Getting close to the water (so you can see it)

- Think about what else is around there
- What do you see when you're turning, what is the experience
- What will the visitor/user experience be from the time the approach the passageway until the time they reach the beach
- Get in touch with local commission on disability
    - Might have good input on folks that would be using it