Shoreline Interventions for Coastal Resilience

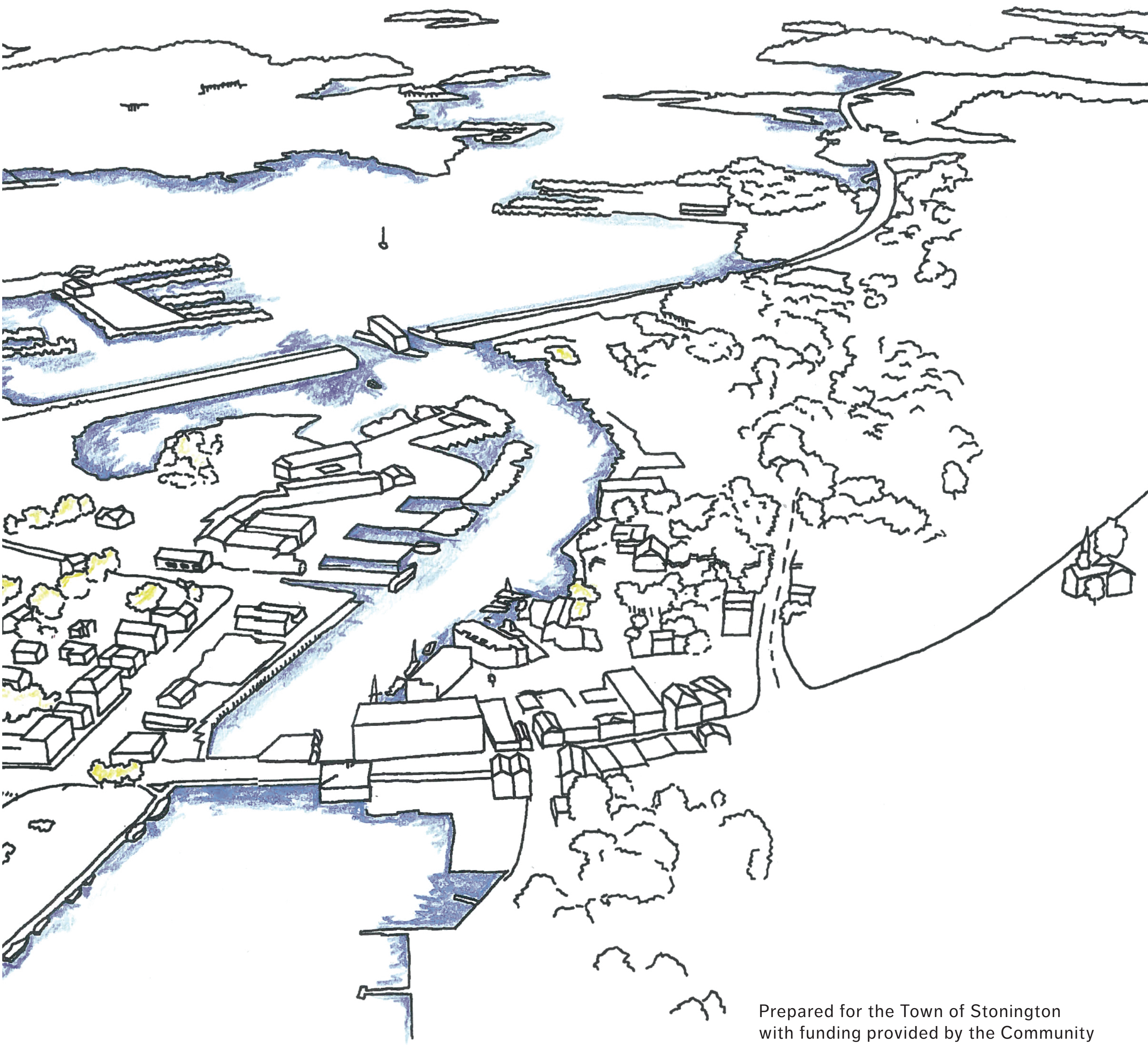

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TABLE OF CONTENTS

We would like to thank Keith Brynes and Scot Deleda from the Town of Stonington, and Adam Whelchel and Cary White from the Nature Conservancy, for the opportunity to work on behalf of the community in Mystic. We would also like to extend a special thank you to residents of Stonington and Groton for their valuable insight and feedback that helped shape this plan.

PROJECT OVERVIEW:
COASTAL RESILIENCE FOR MYSTIC, CONNECTICUT

Mystic is a historic village located along the southeastern coast of Connecticut. The village lies at an estuary, straddling both sides of the Mystic River where it meets the Mystic Harbor. The village extends across portions of the towns of Groton and Stonington.

The name Mystic derives from the Pequot term missi-tuk, a large river whose waters are driven into waves by tides and winds. The Pequot native people established villages along the Mystic River centuries ago and since then, the area has undergone numerous settlements.

Dutch settlers arrived in Pequot territory in 1611. In response, the Pequots joined the fur trade, strengthening their economic and political power in order to extend their dominion into other tribal regions. The arrival of English settlers in the early 1630s shifted the distribution of power in the region (Landry). Tensions escalated between native peoples and Europeans over control of the fur trade, land holdings, and isolated attacks from both sides. The Pequot War broke out in 1636, the first major conflict between colonists and native peoples in Mystic (The Society of Colonial Wars). In 1637, the English massacred up to 500 Pequot people at Mystic Fort. This event, known as the Mystic Massacre, was a pivotal moment in the war that ultimately led to the downfall of the Pequot people. Today's Mystic consists of land that was granted to European veterans of the Pequot War (Pyror).

Throughout the eighteenth and nineteenth centuries, Mystic was an active seaport with a strong economy based on agriculture, manufacturing, and ship building (Connecticut Trust for Historic Preservation). The Mystic Bridge was built in 1819, connecting the east and west sides of the Mystic River (Mystic River Historical Society). Mystic Village developed into New England's primary port for sealing, whaling, and trade; the harbor drew in merchant vessels and sailors from around the world (Mystic River Historical Society). The vibrant economy required extensive development of the coastline to accommodate the visiting ships and sailors. The booming economy allowed for prosperous residents to build structures in Greek Revival and Queen Anne fashion, the most popular architectural styles of the nineteenth century. The narrow streets of downtown, connected by small through-streets that lead to the water, are reminders of this historical building phase. Mystic's history as a seaport hub remains visible in its intact historic districts, museums, and cultural events. Mystic attracts a large tourist crowd in the summer months, drawn to the area for its unique intact village and its boat access.

Centuries of development around the water have resulted in a hardened shoreline, dominated by structures like bridges, piers, docks, and marinas. Shoreline hardening allows human development to come up to the edge of water and land and provides boat access to the water. The coastal area of Mystic is defined by human interventions for business and boating; few natural open areas remain. Land use in Mystic is primarily residential; it is home to approximately 4,000 year-round residents. Today, Mystic Village seeks to balance its historic resources and water access with the anticipated effects of climate change on the coastal community.

The Northeast United States is experiencing an increase in the intensity and frequency of storm events as a result of climate change (USGCRP). The quantity of rain that falls during heavy rain events (defined as the heaviest 1% of all daily events) increased by 71% between 1958 and 2012 (USGCRP 2014). The Northeast is also experiencing the global trend of sea level rise. Rising sea levels will exacerbate the impacts of storm surge, flooding, and erosion on coastal communities (USGCRP).

Floods in Mystic are increasing in intensity and frequency. The village of Mystic has a long history of impact from hurricanes and other storm events. Most recently, the direct path of Superstorm Sandy missed Mystic, yet the area still experienced significant flooding and related storm damages. In recognition of climate change and increased stressors on coastal communities, the Town of Stonington commissioned a coastal resilience plan, published in August 2017.

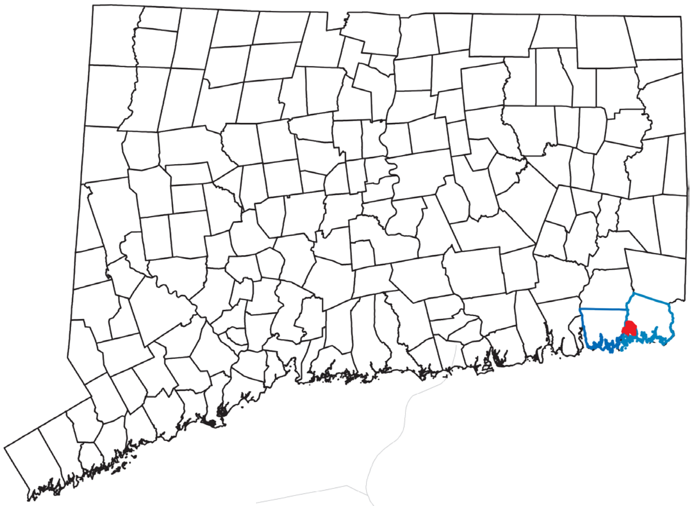
The *Coastal Resilience Plan* employed a three-step approach to address coastal resilience. It established a climate baseline by modelling sea level rise and storm surge on the land. It identified areas at risk within Stonington by factoring degrees of hazard, exposure, and vulnerability. Finally, it developed a broad outline of resilience strategies and next steps. The *Coastal Resilience Plan* is an invaluable resource for the Town of Stonington and its residents. The research and analysis in the *Coastal Resilience Plan* forms the basis for this study.

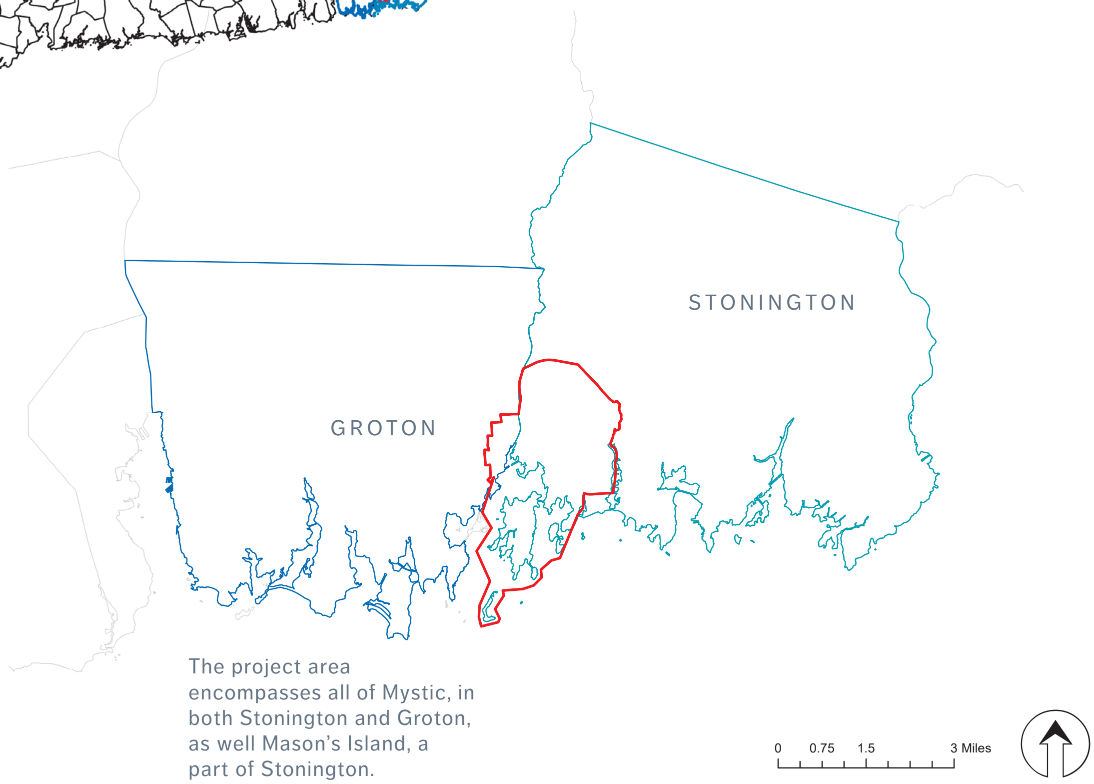
The *Coastal Resilience Plan* identified Mystic as an area at high risk given its geophysical characteristics, including its low elevation and exposure to the water, and its wealth of historic and cultural resources. Mason's Island, a residential barrier island connected to Mystic by a causeway, was also identified as an area at high risk.

In 2019, the Town of Stonington commissioned two reports, *Shoreline Interventions for Coastal Resilience* and *Inland Interventions for Coastal Resilience*, as the next steps in the implementation process of interventions for climate adaptation and mitigation. These reports identify suitable sites for interventions and present illustrative renderings for a defined project area that includes the Stonington and Groton sides of Mystic, and Mason's Island. *Shoreline Interventions for Coastal Resilience* focuses on living shorelines as a strategy to adapt to and mitigate sea level rise and storm surge inundation. *Inland Interventions for Coastal Resilience* focuses on green infrastructure as a strategy to manage stormwater, in response to the trend of increasing precipitation as a result of climate change.

The two plans work independently of each other but can be used in concert to provide a comprehensive view of coastal climate resilience.

The plans include proposed interventions that are site-specific to Mystic Village, Stonington. Yet, the intention is that these recommendations can be modified for application in similar historic communities along the Atlantic coast. Mystic Village has the opportunity to minimize damage to its historic built environment and provision for the effects of climate change, and, in doing so, become a model for other coastal communities.





The project area encompasses all of Mystic, in both Stonington and Groton, as well Mason's Island, a part of Stonington.

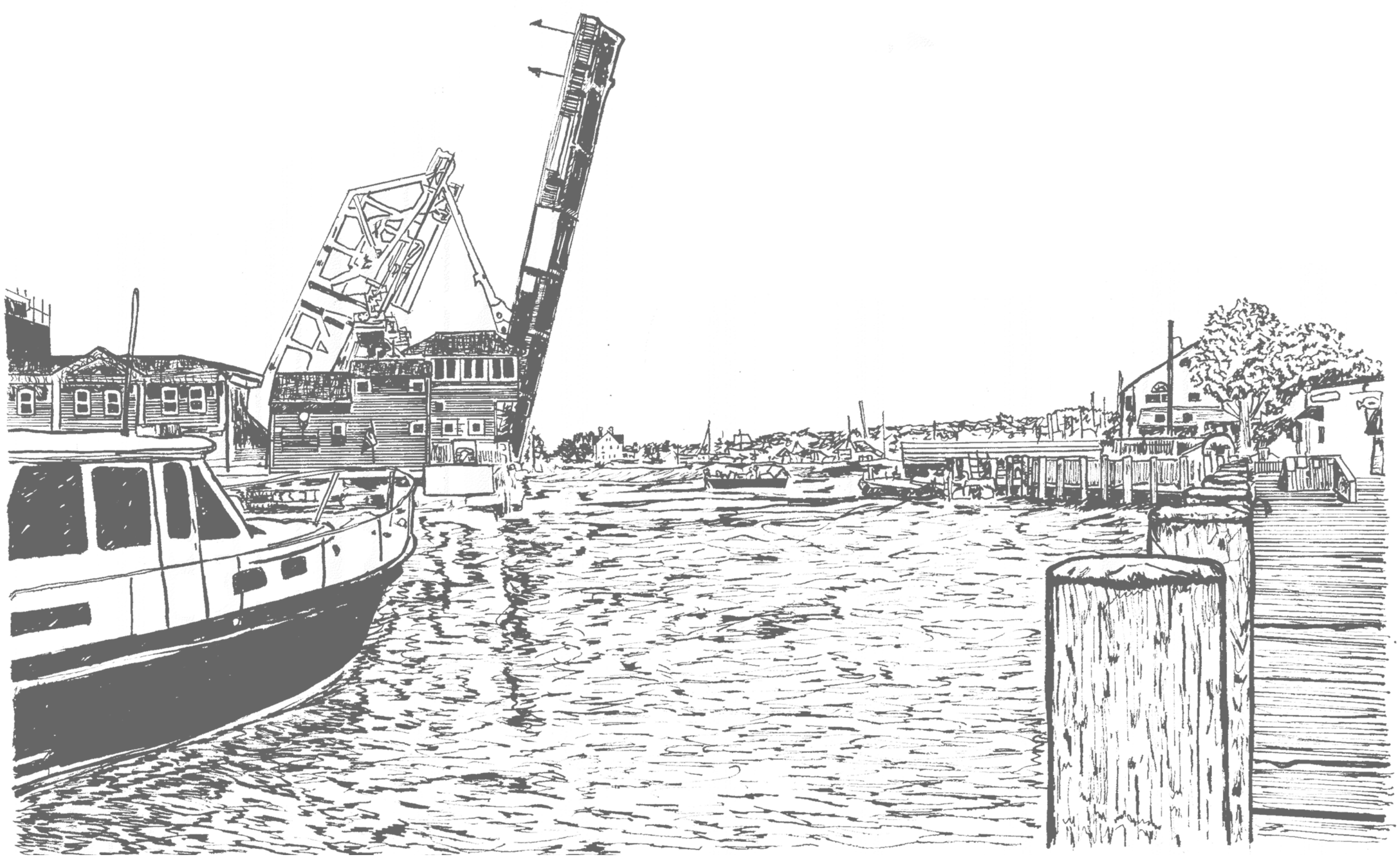
Downtown Mystic experiences a water sandwich effect; pressures of inundation from sea level rise and stormwater runoff from residences at higher runoff accumulate in the low-lying downtown area.

PROJECT GOALS

1. Examine and further develop the living shoreline suggestions from the 2017 Coastal Resilience Plan.

2. Develop a matrix of criteria for types of living shorelines in Mystic.

3. Generate conceptual designs and illustrative renderings.



Executive Summary

The Coastal Resilience Plan, developed for the Town of Stonington in 2017, identified Mystic Village as a highly vulnerable neighborhood due to its low elevation and density of development directly along the coast. The plan broadly outlined a number of coastal resilience measures including the use of living shorelines.

Living shorelines are coastal resilience strategies that use vegetation and natural organisms to create structures that can decrease wave energy, erosion, and storm surge flooding along the coastline. Living shoreline projects mimic or enhance natural ecosystems through design interventions and restoration projects.

In contrast to traditional hard infrastructure, living shorelines can grow and adapt to changing conditions over time making them a particularly attractive approach for coastal protections in light of the continuing future threats of sea level rise. In addition to buffering the coastline from waves and storms, living shorelines can provide many additional benefits to local communities. Living shorelines can enhance coastal habitats, improve water quality, increase green spaces along the shoreline, and provide new growing opportunities for local shellfishing industries.

This report investigates the use of living shorelines in Mystic to increase coastal protections. Based on the landscape of the project area, two types of living shoreline techniques were evaluated in comparison to site conditions: marsh enhancement/creation projects and living breakwaters. Suitability was determined by analyzing landscape characteristics and forces of water movement acting upon the shore. Harbor traffic, development patterns, and existing ecological resources such as tidal wetlands and shellfishing habitats were taken into consideration to balance the protection of both boat access and local ecosystems. Looking at these factor together helped to guide an understanding of where areas of conflict and opportunity might arise for siting living shoreline projects. The result of these analyses indicated that the low-lying elevation of Mystic offers broad opportunities for living shoreline projects, yet dense existing development along the coastline and a busy harbor constrain space for interventions.

Intervention strategies must be developed to maximize protections in a highly developed coastal community with limited space. Prioritizing protections of existing tidal marsh ecosystems and prioritizing interventions on un-devloped land may be one way to approach the challenge of limited space.

Overall, the greatest challenges to implementing living shoreline projects in Mystic will be working with private land owners and negotiating space in an area with high development pressure. In order to achieve community-scale protections, land owners must join together and work across property lines.

The method of evaluating living shoreline suitability developed in this project is meant to be replicable for similar coastal communities. The report is intended to increase awareness of living shoreline techniques, generate deeper conversations about coastal resilience, and inspire the community to take action.


COOPERAGE

What is resilience?

Climate change motivates communities to take action through the creation and execution of resilience plans: these plans anticipate weather-related disasters, factor climate change into planning initiatives, and seek to protect and prolong the healthy functioning of the community.

Resilience is a fluid concept, used across academic disciplines and professional sectors while also used in popular discourse. A planner, ecologist, engineer, and coastal scientist may all define resilience differently. This report references engineered resilience, ecological resilience, and evolutionary resilience.

DEFINING RESILIENCE

Engineers define resilience based on a system with an equilibrium, a steady state. A steady state environment consists of human-induced balance, created through engineered systems and hard infrastructure. Thus, engineered resilience is a mechanical process of bouncing back from a perturbation as efficiently as possible (Vale, 2014). The ability to 'bounce back' or 'return' depends on the strength of the designed environment. To an engineer, resilience is the strength of engineered systems, such as levees and floodgates, against the dynamic forces of climate change and weather-related disasters, such as coastal flooding.

In contrast, ecologists define resilience based on a system that lacks such a permanent steady-state, the supposed equilibrium. Ecology is founded on the principle that humans are one part of an ecosystem, a community of life forms that occupy an area together. Ecosystems are in a constant state of flux, regularly experiencing disturbances and changes. Ecological resilience acknowledges and embraces how ecological systems shift in response to natural or human disturbances. Unlike engineered systems, ecosystem composition is changed post-disturbance; they don't return to a prior state.

EVOLUTIONARY RESILIENCE

In light of climate change, an evolved understanding of ecosystems and evolutionary changes is necessary to define resilience. The Intergovernmental Panel on Climate Change defines resilience as "the capacity of social, economic, and environmental systems to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning, and transformation" (IPCC, 2018). Because the climate will continue to change, human systems must also be able to reorganize and transform. The goal of resilience is to minimize risk to human safety and economic systems during that process. Climate change requires designed systems —and all that is effected, including social and economic systems—to not only bounce back but to reorganize and transform in step with climate system changes.

While climate change is perpetuating evolutionary changes within the environment, resilience must be considered in terms of evolutionary change as well. Coastal resilience need not continuously restore a community to its pre-flood condition or its "steady-state," but rather can involve building systems of dynamism that have the ability to evolve and transform while enduring a storm event (Nordenson et al, 2018). For the sake of this project, the working definition of coastal resilience prioritizes evolutionary changes and ecological principles.

The outlined strategies for resilience that follow focus on the principles of green infrastructure, also referred to as nature-based solutions and eco-engineering. Green infrastructure strategies are founded in the dynamism of the coast, incorporate mitigation and adaptation practices, and seek to recreate and restore natural ecosystem functions when possible.

Engineered resilience is still requisite to preserve the function and stability of human infrastructure, such as roads and homes. Yet, when coupled with ecological resilience, engineered resilience has greater longevity and can contribute to the greater functioning of the system.

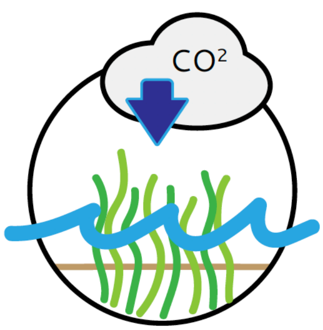
Adaptation versus Mitigation

The far-ranging harmful impacts of climate change can be experienced and seen first-hand through flood events, more frequent and intense storms, and rising sea levels currently occurring in Mystic and world-wide. Preparing a coastal community to better withstand frequent extreme weather events and sea-level encroachment involves the two overarching strategies of adaptation and mitigation. These two strategies may combine to form an integrated adaptation via mitigation strategy.

The Intergovernmental Panel on Climate Change defines climate change adaptation as an “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC, 2001). Adaptation strategies attempt to reduce exposure or susceptibility to climate change induced stressors like flooding and sea level rise. Adaptive strategies include retrofitting buildings to better withstand flood events, elevating buildings, building seawalls, or relocating buildings and people onto higher ground.

Adaptation

Mitigation, sometimes viewed as a subgroup of adaptation, addresses the root causes of climate change and attempts to slow or reverse the effects of climate change (Prettyman, 2015). Mitigation strategies may include reducing greenhouse gas emissions through policy initiatives that shift fossil fuel energy sources to renewable energy or increasing vegetative communities that function as carbon sinks.



Mitigation

Adaptation and mitigation are intrinsically linked; the more we mitigate, the less we have to adapt (El-Ashry, 2019). FEMA has taken steps toward adapting to climate change through zoning by requiring new buildings built within the floodplain to be elevated above base flood level. It is critical for coastal communities like Mystic to consider how their current adaptation strategies can shift to anticipate future storm events and daily tidal inundation from sea level rise. How can communities simultaneously work toward mitigating climate change? Simin Davoudi, editor of *Planning for Climate Change*, considers solely focusing on adaptation strategies to be “analogous to learning that the house is on fire, but instead of fighting the fire, trying to devise methods to live in the flaming structure” (Davoudi, 2012). It is in Mystic’s best interest to establish mitigation strategies like increasing plant communities within the town to lessen the amount of carbon dioxide in the atmosphere. The strategies outlined in this report promote the combination of adaptation and mitigation.

The Design Storm

This document considers strategies for coastal resilience given both current conditions and the near future scenario of 2050, including the most current projections of twenty inches of sea level rise for coastal Connecticut by 2050.

To effectively plan for both current and future risk, coastal resilience projects must take into consideration multiple storm scenarios across scales of magnitude and time. Visualizing the impacts of potential storm surges under both existing and future conditions helps municipalities to prioritize interventions and create cost-effective designs. Yet, the uncertain future effects of sea level rise and increased storm intensities and frequencies potentially induced by climate change can be daunting for coastal communities grappling with large-scale change. This report attempts to balance forward-thinking with approachability by looking at probability data for both 1% and 0.1% scale storm surge events in both current conditions and the near future scenario of the year 2050.

Focusing on changes occurring by the year 2050 is consistent with *Stonington's Coastal Resilience Plan* (2017), which chose to use storm surge probability projections of a 0.1% storm in 2050 as the standard for all community vulnerability valuations. (Stonington Coastal Resilience Plan, 2017). This report also remains consistent with the CRP by using the sea level rise projections of 20 inches by 2050 as a baseline.

This projection has also been verified by researchers at the University of Connecticut, who have developed sea level rise models incorporating local oceanographic conditions for the Connecticut coast. This projection has now become established as the statewide planning recommendation outlined in the *Sea Level Rise in Connecticut Final Report* released by UCONN's Department of Marine Sciences and Connecticut Institute for Resilience and Climate Adaptation in October 2018 (Rath, 2018). Planning for a 20-inch sea level rise by 2050 is a conservative approach, focusing on the upper end of the range of four climate change simulation models related to differ climatic trends and emissions scenarios (O'Donnell, 2018).

The GIS-based climate data used in both the CRP from 2017 and this report was developed by coastal engineers at the Woods Hole Group using probabilistic hydrodynamic modeling that takes into account many, simultaneous physical processes that affect the impact of coastal flooding (Bosma, 2019). These models consider inundation depths, wave velocities, flood pathways, flood volumes, and probabilities of occurrence for thousands of simulated storm events to create dynamic storm surge probability maps (Bosma, 2016). These maps, shown on the following pages, offer a closer look at current and future vulnerability in Mystic.

WHAT IS A 100-YEAR STORM?

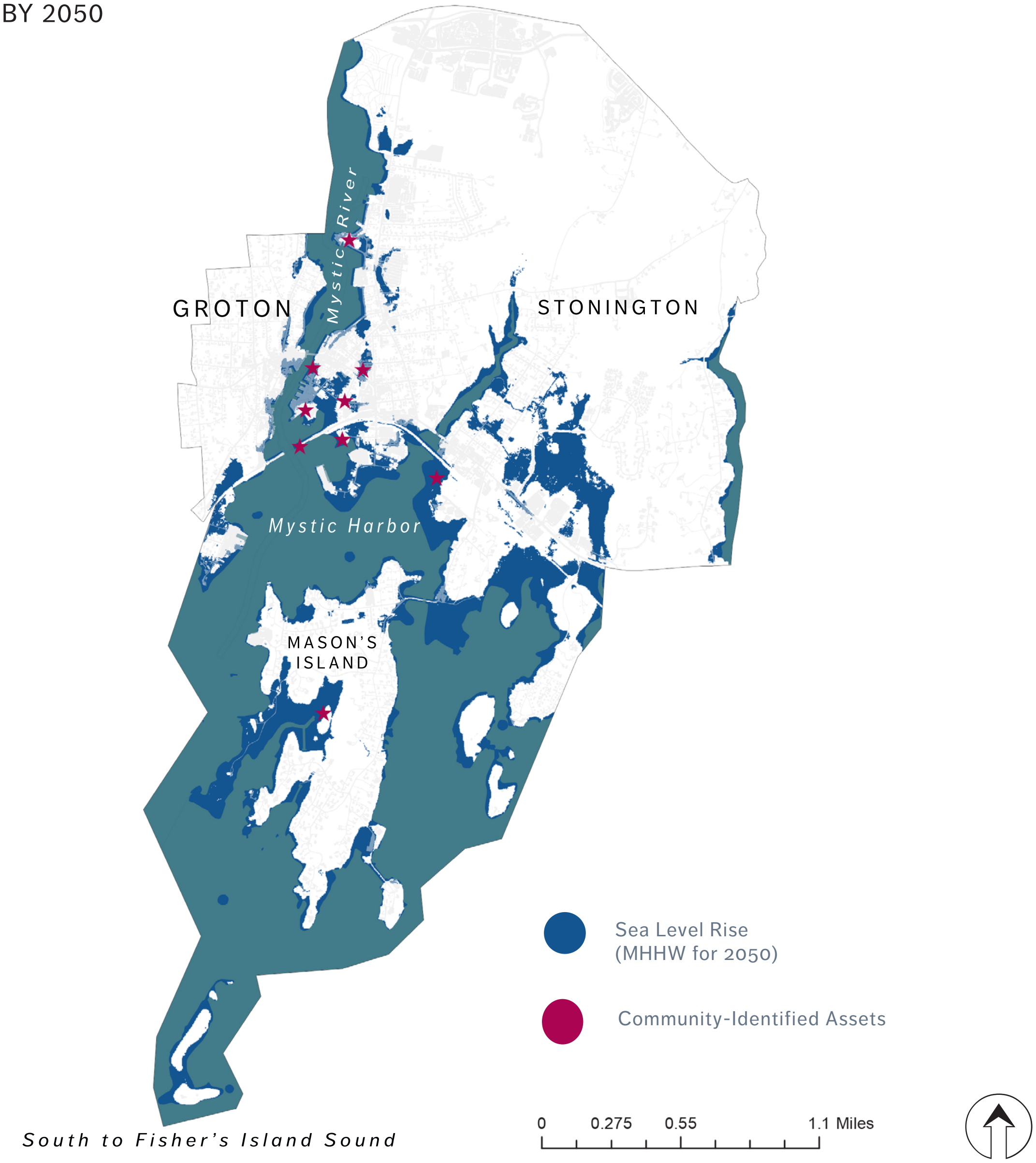
A 100-year storm has a 1-in-100 (1%) chance of happening in any given year, not a storm with a 100-year interval of occurrence. The term has nothing to do with how many years there are between storms, and everything to do with the chance of having a 100-year storm in any given year. A 1,000 year storm has a 1-in-1000 (0.1%) chance of occurrence in any given year.

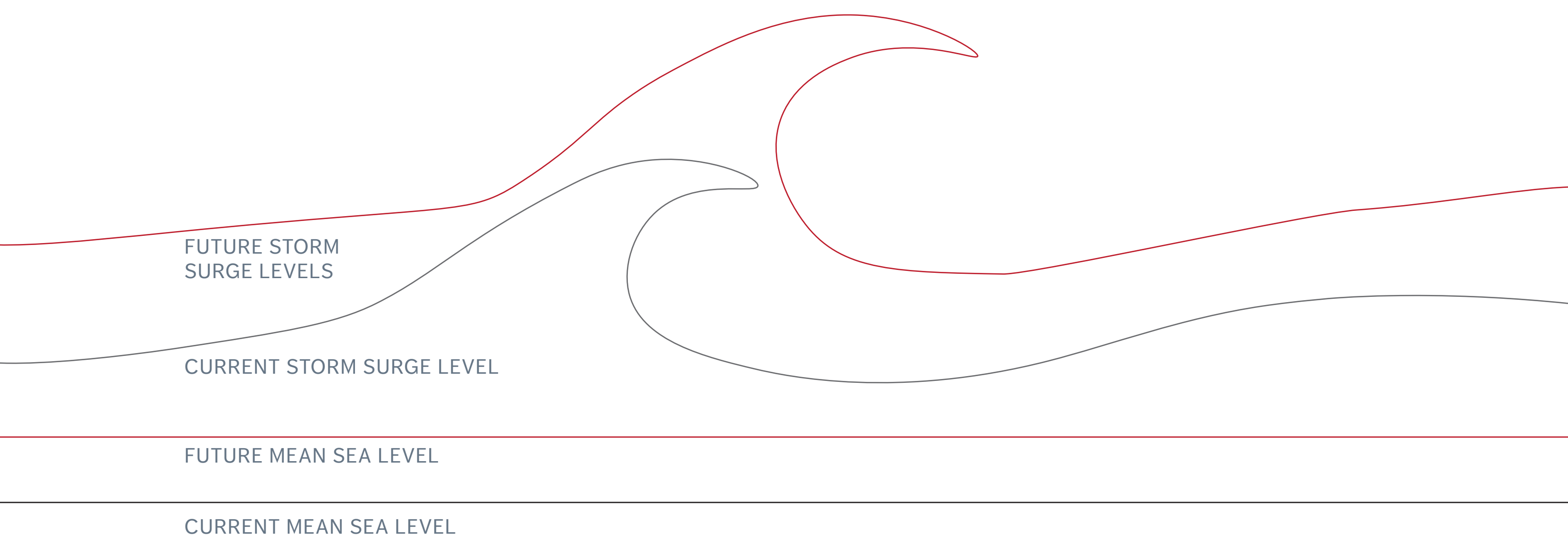
Based on probability theory, a house with a 30-year mortgage located within the 100-year floodplain has a 26% chance of being flooded at least once during those 30 years (Holmes, 2017).

WHERE DOES THE TERM COME FROM?

In the 1960s The National Flood Insurance Program needed to create a benchmark level of flooding to generate a baseline cost of protection across communities (Holmes, 2017). The 100-year floodplain is used to determine flood insurance premiums and building requirements like requiring additional height above base flood elevation, enforced by insurance agents and floodplain managers (Rogers & Hackenburg, 2017).

SEA LEVEL RISE BY 2050





What's at risk?

Resilience is a necessary consideration for coastal communities, like Mystic, that are at increasing risk from sea level rise and inundation from large storm events that will increase in strength and frequency with each passing year.

In recognition of this risk, the Town of Stonington commissioned a *Coastal Resilience Plan* published in 2017. *The Coastal Resilience Plan* defines a coastal risk as the potential for an asset or system to be impacted by a future coastal flooding event (*Stonington Coastal Resilience Plan, 2017*).

In the *Coastal Resilience Plan*, coastal flood risk was evaluated based on the three main factors of hazard, exposure and vulnerability.

> **Hazard** is a measure of the likelihood of a future storm event impacting the community. Coastal storm scenarios, computed and provided by the Woods Hole Group, were used to assess the probability or likelihood of a storm event; the 1% and 0.1% storm scenarios were used.
>
> **Exposure** refers to the depth of flooding that may be experienced by the asset during a given storm event (*Stonington Coastal Resilience Plan, 2017*).
>
> **Vulnerability** is a measure of the impact to the community if the asset is damaged in a flood event, and can be assessed based on economic impact of property damages or impact on valuable assets like Mystic's historic and tourist resources.

WITHIN THE FLOODPLAIN:

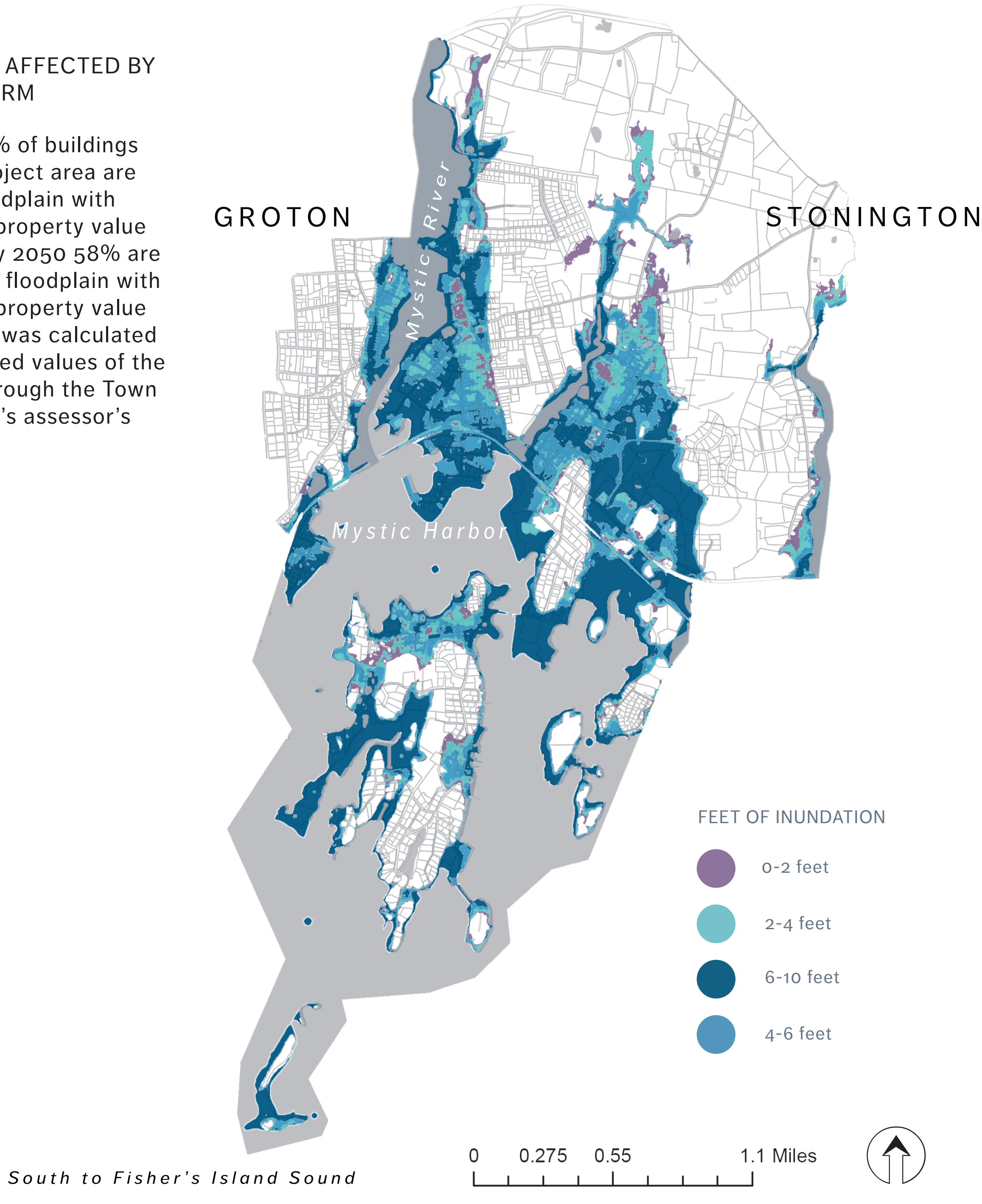
A floodplain is a normally dry area that is subject to flooding from natural water bodies as a result of storms and sea-level rise (Rogers & Hackenburg, 2017). However, storms can be unpredictable and even if a property is not situated within the 100-year floodplain, with enough rain or large enough storm surge, almost any location can flood, and chances of experiencing a flood event increase the closer a property is to the source of water.

LAND AT RISK

Understanding the extent to which flooding will impact Mystic Village will spur coastal resilience planning. Currently 32% of the project area, which includes Mystic Village and its environs, is within the 1% floodplain and 42% is within the 0.1% floodplain. As the years go by, more and more land will be affected by the 1% and 0.1% storm. By 2050, 38% of Mystic will be in the 1% floodplain and 45% will be affected by the 0.1% storm.

PROPERTIES AFFECTED BY 2050 1% STORM

Currently 55% of buildings within the project area are in the 1% floodplain with $486 million property value at risk, and by 2050 58% are within the 1% floodplain with $586 million property value at risk. Value was calculated by the assessed values of the properties through the Town of Stonington's assessor's office.



HISTORY AT RISK

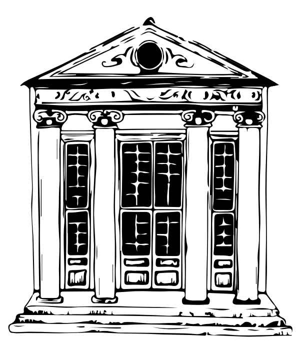
Downtown Mystic contains two nationally registered historic districts: the Mystic River Historic District lies along the west side of the river, and the Mystic Bridge Historic District lies along the east side of the river. The project area contains approximately 351 historical buildings, all of which are either on the national or state registries of historic buildings. The concentration of historical architecture that makes up Mystic's historic districts draws tourists who support the economy of the village and are essential to the character and identity of the community.

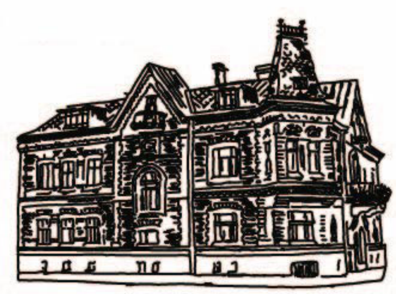
Currently, 62% of the historical buildings are affected by the 1% storm with an estimated property value of $99 million at risk. By 2050, 72% of the historical buildings will be affected by the 1% storm with an estimated property value of $113 million at risk. Value was calculated by the assessed values of the properties using the town of Stonington's assessor's data.

FEMA's National Flood Insurance Program (NFIP) has special variances for historic buildings, landmarks, and sites. Specifically, FEMA offers exemptions for registered historic buildings from floodplain management requirements and provides subsidized flood insurance as long as the historic status is preserved.

Non-historic buildings located within the historic district do not receive special variances, exemptions, or subsidized insurance; these non-historic buildings are required to meet FEMA's elevation standards and other resilience measures.

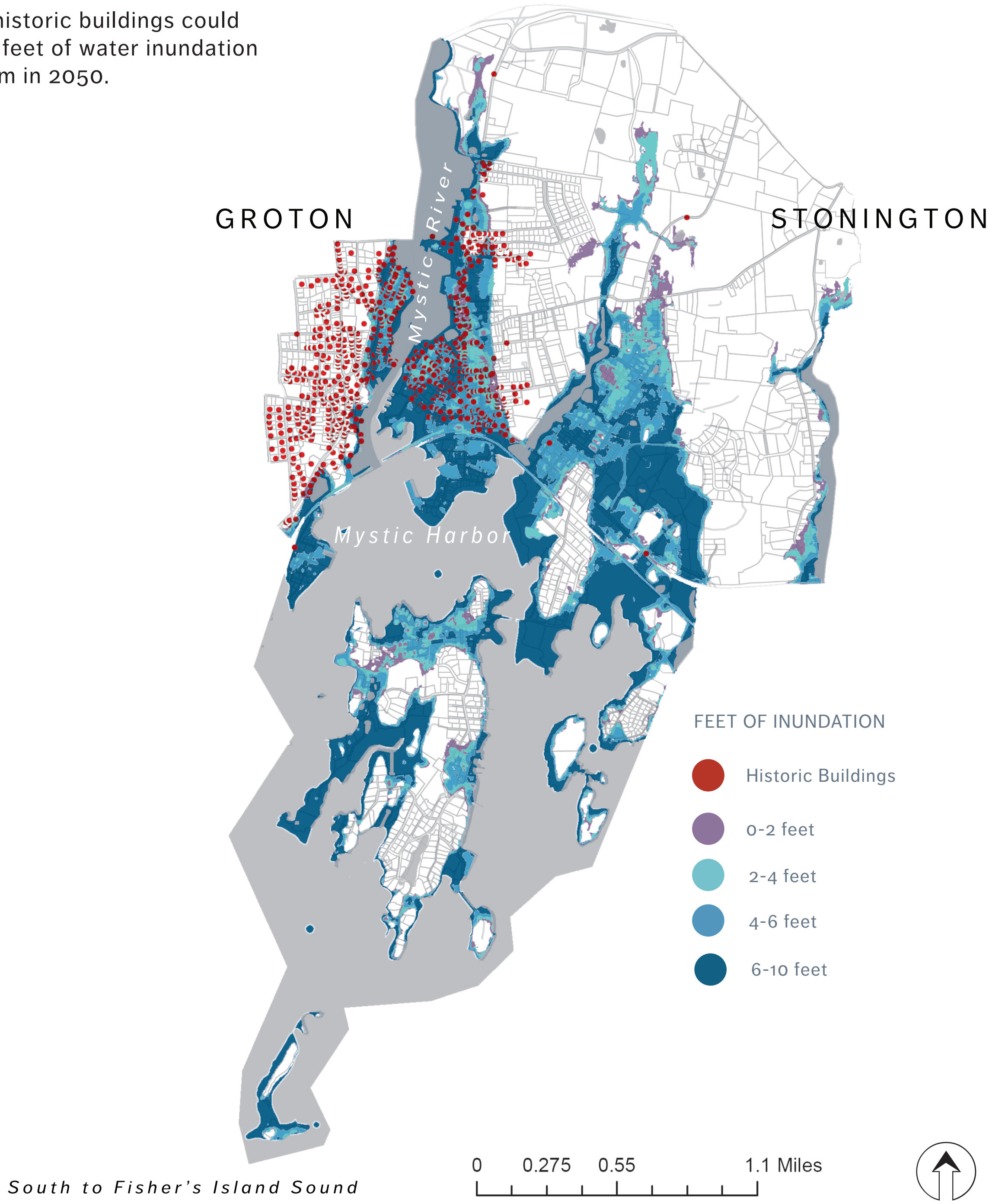
The Town of Stonington follows FEMA's floodplain management exemptions; the Town allows the issuance of variances that exempt historic buildings from the implementation of resilient building codes presently and after a storm event during reconstruction, rehabilitation, or restoration of buildings post-flood (*Stonington Zoning Regulations, 2018*). The town has no adaptation incentives for historic properties that are currently at risk of flood damage, however resilience adaptations would reduce their risk to current and future storm events.





HISTORIC BUILDINGS
AFFECTED BY 2050 1% STORM

The majority of historic buildings could experience 4-10 feet of water inundation during a 1% storm in 2050.



HOW DO WE ACHIEVE COASTAL RESILIENCE?

The need for coastal resilience in Mystic Village is high, given the quantity of land and value of buildings at risk in the current and near future.

The need for coastal resilience is well understood, but the enormity of the need may make it difficult for communities to identify the next steps to implement resilience. Resilience strategies need to attenuate wave action, lessen the impact of flooding on land and infrastructure, and slow the rate of shoreline erosion and immediate risk.

Specific strategies span a spectrum of green to gray infrastructure. Coastal resilience is conventionally approached through shoreline hardening and engineered defenses (Beck et. al, 2013). These gray infrastructure methods use concrete and steel to harden the shoreline, creating a physical blockade against hazards like flood waters. Seawalls and revetments epitomize the gray infrastructure approach to coastal resilience.

Despite the ubiquity of gray infrastructure in coastal areas, there is increasing evidence that gray infrastructure degrades over time and can adversely affect the overall health of the coastline. It is expensive to replace and cannot adapt on its own to changing conditions.

Green infrastructure is an alternative route to implement coastal resilience. Green infrastructure, often connected with nature-based solutions or eco-engineering, uses non-living and living features—like vegetation and sand—to create structures of resilience. Specifically, green infrastructure interventions for coastal resilience are called living shorelines.

WHAT IS A LIVING SHORELINE?

Living shorelines are guided by principles of biomimicry, a design philosophy that looks to natural ecosystems and seeks to recreate their patterns and functions in designed systems. Living shorelines are founded in the recognition that natural shoreline ecosystems—such as a tidal marshes, coral reefs, and dune shrublands—offer protection from coastal hazards and create numerous co-benefits. Intact, healthy coastal ecosystems have an innate capacity to mitigate the challenges, like flooding and sea level rise, currently facing coastal communities.

A living shoreline is an umbrella term; there are numerous categories and subcategories of living shorelines depending on the materials used. Nonstructural and hybrid is a binary categorization for living shorelines that is based on the type of materials used.

NONSTRUCTURAL LIVING SHORELINES exclusively employ vegetation and sediment; for example, marsh creation introduces marsh plant species with roots that stabilize soils, and dune nourishment introduces sand/fill, and vegetation to create a new land feature.

HYBRID LIVING SHORELINES use vegetation and sediment with the addition of some hard structure. Often, the structure introduced is biodegradable and works to ensure the establishment of vegetation before it wears away with time and the elements. Other times, the structure is fixed, made of hard materials such as concrete, and is integrated with organisms like plants and bivalves.

WHY LIVING SHORELINES?
IMPACTS OF GRAY INFRASTRUCTURE ON COASTLINES

Structures to support human settlement in the coastal area are at odds with the ecological processes of the coastline.

The coast is a dynamic zone—multiple forces act upon it, shifting the environmental conditions on a short and long term scale to create a landscape in continuous flux.

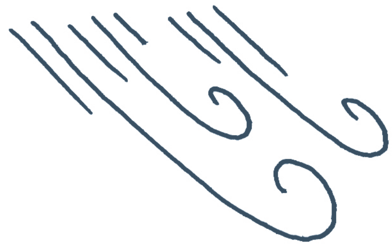
Coastal geomorphology is the study of the physical features of coasts and the processes that form them. Understanding how coastal areas behave—rhythmically or erratically, depending on external conditions—helps inform coastal management decisions (Woodroffe, 2002).

Human-built structures impound or prevent the coast's natural processes; these hard structures attempt to create a steady-state environment that accomodates human communities.

The tension between settlements and coastal processes are compounded by sea level rise and increased inundation from storm events.

WIND

Wind indirectly and directly influences the coast. Wind instigates saltation, the movement of sand across surfaces, which creates new landforms like dunes. Wind indirectly influences the coast through wave formation. Coastal waves are created by offshore breezes and exacerbated during storm events.



PROCESSES ACTING UPON THE COAST

WAVES

Waves are a product of wind and tidal energy; waves constantly transform the coast by moving sediment (Woodroffe 2002).

Coastal structures, like sea walls and revetments, reflect wave energy, creating deeper and stronger wave reverberations. New wave energy erodes the soil at the base of coastal structures, leading to the destabilization of the structure over time.

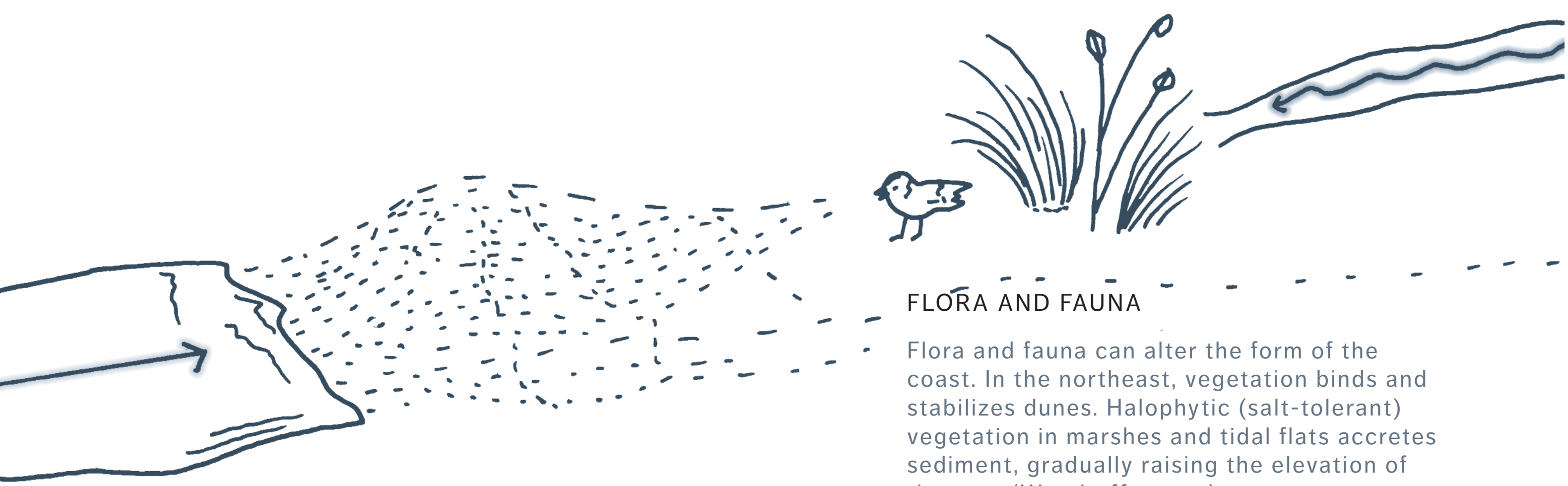
The coast of Mystic is in an estuarine environment and sheltered by Mason's Island; therefore, wave energy is relatively low. In contrast, the east and south edges of Mason's Island are exposed to more wave energy from the ocean.

TIDES

Tides subject the coastline to a daily rise and fall of long waves. Tide levels define the intertidal and subtidal zones of the coast which are areas of high biodiversity.

Shoreline and flooding structure, like seawalls and embankments, encroach on the intertidal zone from the land, leading to an overall reduction in area. Such structures also prevent the inland migration of the intertidal zone, a response to wider coastal changes and sea level rise. (Guidance on Selecting Mitigation Measures).

Rivers and estuaries input sediment along the coastline, especially during floods.



FLORA AND FAUNA

Flora and fauna can alter the form of the coast. In the northeast, vegetation binds and stabilizes dunes. Halophytic (salt-tolerant) vegetation in marshes and tidal flats accretes sediment, gradually raising the elevation of the area (Woodroffe 2002).

Shoreline armoring changes the biology of coastal areas by reducing or destroying the intertidal zone, altering hydrology and sediment transport. The intertidal zone, hydrological function, and sediment deposition are the physical characteristics that define habits for flora and fauna along the coast.

Hard structures lead to placement loss, the the loss of coastal habitat from the direct footprint of the structure. The larger the hard structure, the greater the loss of habitat (Dugan et. al, 2018).

Hard structures result in an overall reduction in the abundance and diversity of life forms due to the loss in habitat area and

SEDIMENT

Wind, waves, and tidal flows transport sediment, like sand along the coast. Sediment erosion, transport, and deposition build coastal landforms.

When waves and tides are interrupted, the processes of deposition and erosion of sediment along the coast are changed. Hard structures, such as groins, impound sediment and direct land massing, changing the landscape of the coastline.

WHY LIVING SHORELINES?
THE BENEFITS OF GREEN INFRASTRUCTURE

The creation of living shorelines for coastal resilience is a relatively nascent practice in comparison to the use of gray infrastructure, and evidence of its long-term success is in the process of being gathered.

Despite the short history of its use, living shoreline strategies are attractive options for communities. Living shorelines seek to mimic natural ecosystems; there is a developing body of scientific literature on the role of ecosystems in natural disaster mitigation, its cost-effectiveness, and the associated co-benefits (Beck et al. 2013). Living shorelines are an iteration of ecosystems built by humans that are capable of providing similar services for natural disaster mitigation.

Like ecosystems, living shorelines offer co-benefits and ecological services. A co-benefit is defined as an additional benefit related to an action that is not the primary goal of the action. An ecological service is a co-benefit that relates exclusively to the function of a greater ecosystem, like a watershed.

For instance, in a living shoreline project, The Nature Conservancy installed oyster reefs in the Gulf of Mexico. The oyster reefs functioned successfully to attenuate wave action, reducing the height and energy of the highest 10% of waves, but also "translated to more than 6900 pounds of additional catch per year and removal of up to 1888 kilograms of nitrogen per year from surrounding nearshore waters" (Sutton-Grier et al, 2015).

Living shorelines typically have a relatively low cost of implementation compared to gray infrastructure, such as seawalls and bulkheads, that erode over time under the pressures of salt water and wave energy. In contrast, living shorelines are composed of natural materials that thrive in salty aquatic environments and are capable of shifting and growing on their own with minimal human interference and .

SERVICES OF LIVING SHORELINES

COASTAL GEOMORPHOLOGY

Living shorelines allow for the natural dynamic processes of the coast to occur, such as the forces of wind, tides, waves, and biological processes. In contrast to gray infrastructure, like sea walls, living shorelines absorb and shift in response to these forces, which contributes to the greater health of the coastline.

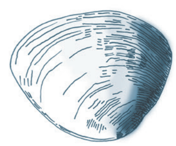
MITIGATION

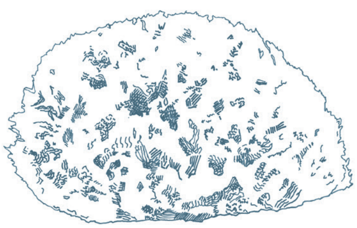
Living shorelines offer not only adaptation to climate change, but also mitigation as well.

Living shorelines use vegetation for multiple purposes. One benefit of using vegetation is carbon sequestration which can slow the rate of global warming.

ADAPTATION

Living shorelines buffer inland areas from the forces of open water, like storm surge and flooding. Spatial buffering is a form of adaptation to climate change because inland assets experience less damage from sea level rise and storm surges.





POLLUTION MANAGEMENT

Living shorelines feature vegetation and promote bivalve habitat. Both vegetation and bivalves, like oysters, can improve water quality through filtration of nutrients and other pollutants.

WILDLIFE HABITAT

Living shorelines create wildlife habitat. By introducing vegetation, sediment, and soft structures, living shorelines provide new grounds for shelter and nursery for regional wildlife.

AESTHETIC DIVERSITY

Living shorelines read as natural coastal features, which can appeal to tourists and residents.

Living shorelines seek to mimic the structure and function of four natural ecosystems.

BEACH

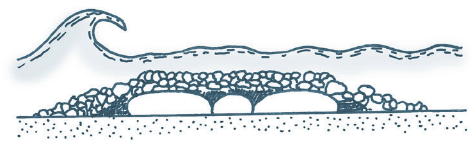
Beaches are naturally occurring coastal environments that consist of sand and minimal vegetation. Beaches form in response to waves, tidal currents, and wind that all move sand across the coastline. Beaches are a natural landing strip for waves and water along the shore. Beaches offer coastal resilience because they are a malleable space between open water and on-land assets.

LIVING SHORELINE STRATEGY: Beach nourishment, the practice of replenishing sand, is a living shoreline strategy that functions to replace the sediment that has been washed away.

DUNE

Dunes are mounds of sand formed by the wind. Dunes, given their increased elevation, intercept wind and water moving inland from the ocean. Dunes can reduce and delay flooding of inland areas and assets, while also providing habitat for wildlife and storing sand for neighboring beaches.

LIVING SHORELINE STRATEGY: Create dunes and supplement existing dunes by building structural integrity and stabilization with vegetation and internal supports, like coir tubes.



MARSH

Tidal marshes are dynamic wetland ecosystems located between the high and low tide levels. They are subject to daily inundation and are an area of high biodiversity. They offer numerous ecosystem benefits including carbon sequestration, wildlife habitat, soil stabilization, and softened wave impact.

LIVING SHORELINE STRATEGY:
Create marshes and enhance existing marshes through planting vegetation and adding soil where necessary.

OFF-SHORE REEF

Reefs, both artificial and natural, attract a diverse range of marine organisms. Marine organisms are attracted to structures for shelter and other benefits.

Reefs create small whirlpools around them, forming a unique underwater environment that slows wave energy and currents, while also building up sediment around them.

LIVING SHORELINE STRATEGY:

Build off-shore reef structures called living breakwaters. Living breakwaters combine the function of hard breakwaters and off-shore reefs to create new shallow water landscapes that protect inland areas.

WHICH LIVING SHORELINE FOR MYSTIC?

This project assesses the suitability of two living shoreline strategies: marsh-based and living breakwaters. The coastal area of Mystic is an estuarine environment, situated in an area sheltered from direct forces of the ocean, primarily strong winds and waves that form beaches and dunes. The land of Mystic is ill-suited for sandy beaches and dunes; in contrast, the area has naturally occuring tidal marshes and existing shellfish beds. The analysis section of this report explores potential locations for these two techniques.

MARSH-BASED LIVING SHORELINES

Marsh-Based Living Shorelines employ native tidal marsh plants to stabilize shorelines, reduce wave energy, and create coastal habitats.

Marsh-Based Living Shorelines are well-suited to environments with wide, gently-sloped intertidal zones with low wave and wake energies. Locations of historic tidal marshes are often suitable for Marsh-Based Living Shorelines as they meet the physical requirements for the success of tidal vegetation, unless the hydrology of the region has been irreparably altered, for example, by gray infrastructure.

In addition to vegetation, some locations require the addition of structural components, like coir logs. Structural components create an edge between the marsh and open water, which stabilizes the edge from erosion. Site analysis is necessary to determine whether the site requires the addition of such structural components.

RESILIENCE

Tidal marshes can enhance coastal resilience by acting as nature's "sponges." Tidal marsh ecosystems can absorb wave energy during coastal storms and the regular tidal flows. During large rain events, tidal marshes absorb rain water quickly, thereby reducing the pace of stormwater runoff.

CO-BENEFITS:

Tidal marshes can filter and absorb pollutants from land runoff, protecting and improving area waters (Chesapeake Bay Program).

Tidal marshes are among the most effective natural areas at carbon sequestration; research shows that tidal marshes are capable of trapping up to 50 times more carbon in the soil then the same area of tropical forest (Naturally Resilient Communities).

Over 50% of commercial fish and shellfish species in the United States rely on coastal wetlands for food, shelter, or nursery ground (Bonsack, 2016).

About 45% of endangered/threatened species rely on estuarine and coastal wetlands for survival; many specifically need salt marshes (Bonsack, 2016).

CONSIDERATIONS:

Coastal wetlands in general are currently lost at a considerable rate in the U.S. due to urban and rural development. Land use changes in proximity to coastal wetlands alters the overall hydrology of the region and increases the quantity of runoff.

Tidal marshes are endangered by sea level rise; as the high tide level moves inland, tidal marshes must keep pace to avoid constant inundation. Along highly developed coastlines, there is often not sufficient or suitable space for tidal marshes to move inland.

MARSH CREATION

Marsh creation involves converting suitable non-vegetated, intertidal areas to tidal marshes. At these sites, marshes can be created by planting into the existing substrate or introducing fill to raise the elevation and then planting into it.

MARSH ENHANCEMENT

Marsh enhancement involves augmenting degraded, sparsely vegetated existing tidal marsh areas. By installing new marsh plants and implementing new management practices, existing tidal marshes can expand and improve, thus providing increased coastal resilience.

Marsh enhancement sometimes requires the addition of clean dredged sand to raise the elevation of the marsh area. Higher elevation is often necessary to maintain the marsh's location within the intertidal zone as sea levels rise.

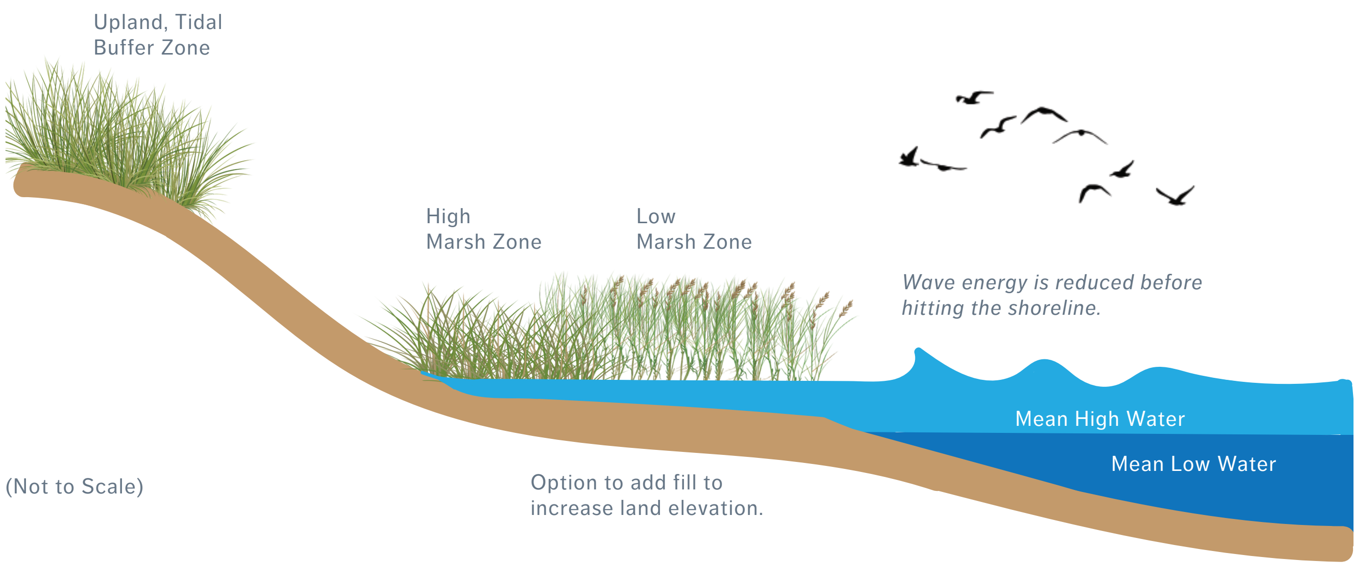
WHAT GROWS IN A MARSH?

Tidal marsh plant species are dependent on the local salinity, water depth, and duration of daily tidal inundation.

Salt marshes can be extremely difficult places to live because of daily fluctuations in water level, temperature, oxygen, and salinity; therefore a small number of plant species are well-suited to salt marshes. Salt marsh plants are salt-tolerant and adapted to water-levels that fluctuate with the tide.

A healthy marsh typically forms two zones for marsh species - low marsh and high marsh. Low marsh species are located along the seaward edge of the marsh and are usually flooded in every high tide and exposed in every low tide. The predominant low marsh species is smooth cordgrass, *Spartina alterniflora*.

The high marsh area stretches from the low marsh landward to the upland zone. High marsh soils are only flooded during high tide events. However, the soil still tends to be saturated and the plant diversity suited to high marsh is also low. The dominant species include grasses and rushes, like salt hay grass, spiked grass, and black grass.



CASE STUDY: MARSH ENHANCEMENT WITH TOE IN NORFOLK, VIRGINIA

The City of Norfolk, Virginia saw an opportunity to redesign a degraded segment of shoreline along the Lafayette River to showcase living shoreline techniques, strengthen coastal protections, and improve public access to the waterfront. This stretch of shoreline previously contained dumped construction debris and a denuded marsh experiencing subsidence and invasion by non-native species. Restoration of this degraded area involved addressing local erosion, increasing the space's resilience to future sea level rise, and creating space for educational programming. The City also sought to use this project to encourage private landowners to implement similar living shoreline erosion control techniques (Clark Nexsen).

The City employed two engineering firms that used GIS modeling of the underlying conditions to run preliminary suitablity analaysis. Two areas of living shorelines, measuring 1,100 linear feet in total, were then installed along both sides of the river. First sand was added to the shore to increase the elevation and expand the shoreline area. Native marsh grasses were planted in the low marsh area with both coir logs and rock sill to reduce wave energy at the marsh edge (Adapt Virginia). An upland riparian buffer zone was planted to reduce stormwater runoff draining onto the property, as required by the Chesapeake Bay Preservation Act (Clark Nexsen). A living classroom for the nearby school was constructed near the water's edge and breaks in the sills were integrated to allow access for kayakers and other recreational users (Adapt Virginia).

Many lessons were learned in the process, including the importance of using animal fencing to protect newly established plants, consideration of the erosion impact of upland stormwater on the lower marsh, and using the appropriate equipment for construction. During the construction process, there were challenges with equipment sinking into the freshly added sediment. The loading capacity of the newly in-filled marsh area was the primary concern in choosing the right equipment. The design process also benefited from involving public input and integrating multiple living shoreline techniques into one design (Parkinson, 2016).

Today, the Colley Bay Project is completed and the site is considered a highly valued community space. The Colley project is representative of the importance and success of restoring coastal wetlands. Local volunteers from local universities and environmental groups work to inventory the plants and animals living within the restoration sites, helping to monitor the long term success of the project (Raper, 2013). Overall, community involvement through stakeholder consideration and volunteer engagement early on in the installation process helped make the project an overall success.

PROCESS

Analysis of Substrates, Fetch, Intertidal Slopes, Shoreline Erosion (digitized from aerial photos), Sea Level Rise

TAKEAWAYS

Animal fencing necessary for the establishment of marsh plants

Analyzing upland storm water runoff effects on plant establishment is essential to the design process

Use appropriate equipment and machinery for landforming along shore

DETAILS

Status: Completed in 2012

Location: Colley Bay, Norfolk, Virginia

Construction Timeline: 2011-2012

Stakeholders:

- The City of Norfolk
- Community and landowners
- Volunteers and students

Designers:

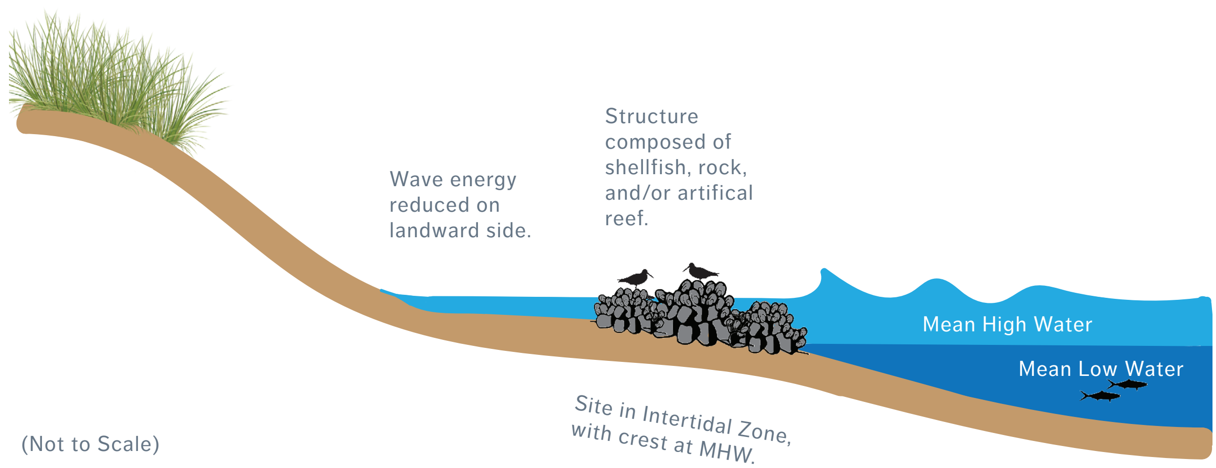
- BayLand Consultants
- Clark Nexsen, engineering

Funding:

- NOAA Chesapeake Bay Trust
- Norfolk Wetlands Board
- Norfolk Planning Department
- Norfolk Public Works

Breakwaters are structures, typically made of concrete or rock, designed to reduce the energy and intensity of waves so inshore waters remain calm and communities are better protected from storm surge (Sciortino, 1995).

Living breakwaters, like conventional breakwaters, are located offshore. They protect the nearshore land from wave damage by creating a shallow water landscape that intercepts, slows, and calms incoming waves. In contrast to hard breakwaters, living breakwaters are intentionally designed to incorporate natural habitat components and serve as a scaffolding for life. The materials they are made from attract marine species like algae and bivalves.



RESILIENCE

Breakwaters can enhance coastal resilience by acting as nature's porous seawall. Breakwater ecosystems can absorb wave energy during coastal storms and the regular tidal flows; as strong waters move towards the land, breakwater forms create friction that downshifts the velocity.

Living breakwaters create a shoaling effect; a shoaling effect is the change in the velocity of waves that occurs when the water encounters friction, like an oyster structure, on the ocean floor (Risinger).

CO-BENEFITS:

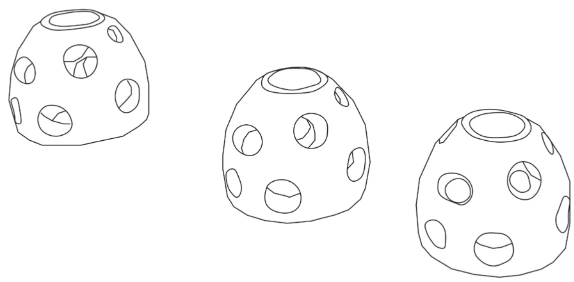
Living breakwaters create new habitat areas for aquatic species such as shellfish, finfish, and crustaceans to proliferate.

Shellfish filter nutrients and pollutants from water and create a healthier marine ecosystem for marine life.

Living breakwaters create a biodiverse calm-water zone that is prime for recreation, specifically recreation with an environmental educational component.

CONSIDERATIONS:

Living breakwaters, when established in conjunction with marsh habitats, creates a synergistic system where the breakwater accumulates sediment landward for marsh plant species to latch onto and continually grow further offshore. Living breakwaters may contribute to the health and longevity of tidal marshes in light of sea level rise, which threatens tidal marshes.



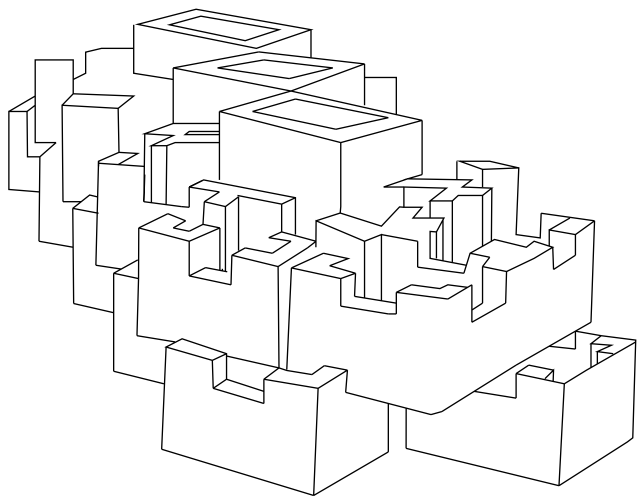
REEF BALLS

Dome-shaped concrete structures that mimic the natural structures of reefs.

Reef balls are engineered with a heavy bottom to ensure they won't be toppled over when a wave hits. Water can move throughout the numerous holes in the structure, creating small whirlpools that creates a downward velocity to keep the reef balls in place. The structures can also be anchored by driving ~3 piles into the sea floor ~2 feet (Reef Ball Foundation, 2008).

OYSTER CULTCHES

Oyster cultches are wire bags or cages that are filled with natural media, like shellfish shells, stones, and silt. The bags are natural beds for oyster spawning; oyster larvae attach to the natural media and grows. Oyster cultches protect shorelines from incoming waves and allow sediment to slowly build up landward of the structures. The energy of waves is dissipated as the water moves through the beds.



OYSTER CASTLES

Concrete structures that resemble castles interlock and stack on top of each other.

The structure, with its many edges and tucked away surfaces, provides many surface areas that attract and foster oyster settlement, attachment, and growth.

The castles are versatile in that their configuration can be customized to different heights and widths.

Stratford Point, formerly a Remington Arms Gun Club, harbored large amounts of accumulated lead in bullet remnants throughout its 40-acre parcel on the coast of Connecticut. Remediation efforts to remove bullet remnants severely degraded the tidal fringe marsh that once inhabited an intertidal zone, and efforts to restore the intertidal marsh failed due to Superstorm Sandy. The Stratford Living Shoreline Project aims to restore and manage 12 acres of intertidal marsh habitat, and 28 acres of coastal upland, and to protect them from storm events by installing reef ball structures. These structures dampen incoming wave energy and promote sediment accretion, which helps to bury residual lead.

In 2011, dunes were reconstructed with underlying geotubes, large sediment filled tubes, to help protect upland vegetation from storm surge and erosion. In 2014, 64 reef balls were installed, spanning 150 feet in length with over 3,500 *Spartina alterniflora* marsh plants planted within the intertidal zone. Since beginning the Living Shoreline Project, an additional 372 reef balls support approximately 40,000 *Spartina* marsh plants, 800 individual woody plants, and 35 different species of trees and shrubs in the uplands (Mattei, 2017).

Four years of monitoring indicates that the artifical reef structures are functioning as designed. A 35% reduction in wave intensity and height during storms, and significantly reduced rates of shoreline erosion have been observed. It was found that up to two feet of sediment was deposited on both sides of the structures, which enables the planted marsh species to continue to develop and advance. Flourishing habitat has been observed where large numbers of aquatic species, like fish and oysters, are living in or on the structures themselves.

The project could serve as a "proof of concept" and be used as a model for nature-based solutions to prevent shoreline erosion, lessen wave energy, and restore wildlife habitat (Mattei, 2017).

PROCESS

Analysis Performed: Bathymetry, storm wind and wave trajectory, wake energy, fetch, sediment loads, sea level rise, erosion rates, existing natural communities.

TAKEAWAYS

Timing and sequencing is essential for a successful project. 30,000 beach grass plants and initial dune installation were eroded and destroyed by Superstorm Sandy before reef balls were installed. Installing reef balls first would have protected the marsh and dune from the storm.

DETAILS

Status: Installation complete.

Monitor & Maintain: By a team of researchers led by Jennifer Mattei, restoration ecologist.

Location: Stratford, Connecticut

Construction Time Frame: 2011-2018

Participants:

- Sacred Heart University
- CT Audubon Society, site manager
- DuPont Company, site owner
- Housatonic River Estuary Commission
- CIRCA & CT DEEP, Bureau of Aquaculture
- US Army Corps
- Town of Stratford

Funding:

- Long Island Sound Futures Fund
- US Army Corps
- 2017 National Oceanic and Atmospheric Administration: Coastal Resilience Grant
- National Fish & Wildlife Foundation

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Reef balls line the shoreline of Stratford, Connecticut, protecting the inland with a 35% reduction in wave energy.

Analysis

Living shorelines along the coast of Mystic are applicable nature-based alternatives to shoreline armoring and could enhance natural habitat while creating a more resilient and climate-ready community.

Mystic, like most coastal communities, is vulnerable to destructive flood events, sea level rise, and intense storms, all of which are predicted to be compounded over time by climate change. While the ideal situation would establish a protective natural buffer along the entire coast of Mystic, it's important to prioritize areas that are of highest vulnerability, with suitable site conditions for living shoreline implementation, and are compatible with current use.

The focus areas for living shoreline interventions were determined through analysis using engineering criteria for specific types of living shorelines that included tidal range, elevation, fetch, landward slope, bathymetric slope, and erosion. In addition to examining where along the coastline the engineering criteria are met, analysis of additional existing conditions-existing wetlands, current land use, zoning, harbor circulation, and shoreline structures- informed site determination for living shorelines. Feedback from two community meetings provided additional data and insight into areas and assets considered important amongst members of the community, where living shorelines could help protect from storm events.

Outline of Applicability

There is no one-size-fits-all design for living shoreline projects. The different types of living shoreline techniques require different site conditions.

The matrix on the following page outlines a number of characteristics relating to landforms and water movement forces acting upon the shoreline that are often used to assess the suitability of living shoreline techniques for a given location.

An accompanying table defines value ranges for each of these criteria. The criteria and associated value ranges were determined by a review of past living shoreline and applicability modeling projects in the Chesapeake Bay area and New England, and represent emerging industry standards for site assessment.

This matrix offers a preliminary tool for planners, natural resource managers, and property owners for understanding the constraints related to living shoreline implementation and identifying features of the different living shoreline techniques.

The analyses on the following pages further define these criteria and discuss how they apply to the site conditions in Mystic.

TABLE 1: SHORELINE CRITERIA VALUE RANGES TABLE

Criteria	Definition	Ranking	Value
Fetch	Distance wind travels over water to create waves; represents wave energy	High	greater than 5 miles
		Moderate	between 1 - 5 miles
		Low	less than 1 mile
Tidal Range	Height difference between the mean low and high tide	High	greater than 9 ft
		Moderate	btw 3-9 ft
		Low	less than 3 ft
Tidal Zone	Appropriate placement on the shoreline slope	Above MHW	depends on site
		Intertidal	depends on site
		Subtidial	depends on site
Landward Slope	Slope of coastal area located above MLW, in percent	Steep	greater than 33%
		Moderate	btw 20-33%
		Low	less than 20%
Bathymetric Slopes	Nearshore underwater slope, in percent	High	greater than 33%
		Moderate	btw 20-33%
		Low	less than 20%
Erosion Susceptibility	Erosion susceptibility based on K factor	High	greater than 0.4
		Moderate	btw 0.2 to 0.4
		Low	less than 0.2

Table 1 lists the shoreline criteria used in the applicability matrix below, with brief definitions and designated value ranges. The value ranges reflect a range of conditions that may exist along a coastline.

The listed criteria and associated value ranges provided in Table 1 and Table 2 were adapted from research developed by The Nature Conservancy (TNC, 2017) and engineering institutions including the Stevens Institute of Technology in New Jersey (Miller et Al, 2016) and the Virginia Institute of Marine Science located in Gloucester Point, Virginia (Hardaway et Al, 2010).

TABLE 2: SHORELINE CRITERIA APPLICABILITY MATRIX

Living Shoreline Technique	Fetch	Tidal Range	Tidal Zone	Landward Slopes	Bathymetric Slopes	Erosion Susceptibility
Marsh Enhancement or Creation	Low	Low to High	Intertidal or Above MHW	Low	Low to Moderate	Low to Moderate
Living Breakwater	Moderate to High	Low to Moderate	Intertidal or Subtidal	Low to Steep	Low to Steep	Low to High

Table 2 outlines the appropriate ranges of relevant shoreline criteria for the two living shoreline types assessed in this report. The following analyses will investigate if and where these conditions are met along the coastline in the project area.

Fetch

Fetch is the distance over which wind acts on the water surface to generate waves and is often used to represent natural wave energy affecting a stretch of shoreline (Guidance for Flood Risk, 2016). Wave energy is one of the most definitive factors in determining the applicability of one type of living shoreline over another in a given location (Hardaway et Al, 2010). Accordingly, evaluating fetch is an essential step in determining site compatibility. Only low fetch conditions are appropriate for marsh enhancement/creation projects, while living breakwaters can be installed in areas with a range of fetch, but are more useful in areas with high fetch.

Ocean waves are created by wind moving over the water. A number of factors contribute to the intensity of ocean waves, including wind speed, wind direction, and fetch. Generally, fetch is described as the most determinant factor for wave energy and size (Hardaway et Al, 2010). The larger the fetch along a stretch of shoreline, the larger the potential wave energy affecting the shoreline and the larger potential for erosion of the shoreline. Accordingly, the larger the fetch the more buffering capacity is needed to adequately protect the shoreline.

Living breakwaters are hybrid, structural techniques more suited to areas of higher wave energy. They can withstand higher wave forces and work to dissipate the energy before it reaches the shore.

While marsh enhancement/creation projects can also offer impressive wave attenuation during storm surges, tidal marshes are less successful in areas of consistent high wave energy such as area with exposure to the open ocean and thus high fetch. As vegetation-only, soft infrastructural techniques, marsh-based living shorelines can withstand less average force than living breakwaters. Tidal marsh plants have a limit to the amount of regular wave energy they can withstand. Studies suggest that tidal marshes have a survival rate of 44% in areas of moderate fetch (Perry et Al., 2001). Tidal marshes naturally grow in locations sheltered by surrounding landforms such as estuaries, bays, and coves. The low wave energy in these areas creates gently sloping intertidal zones where remaining waves can dissipate over the space of the marsh. Marsh enhancement/creation projects are best suited to areas that mimic this natural habitat. If a potential site for a marsh enhancement/creation project is within a higher wave energy environment (e.g. subject to waves from boat traffic), including a protective structure at the toe of the marsh, located at the low tide line, is needed for the successful establishment of the new vegetation. In these conditions, the marsh toe/sill technique is more appropriate (TNC, 2017).

SUITABILITY:

MARSH ENHANCEMENT/CREATION

Low fetch conditions are appropriate for marsh enhancement/creation projects.

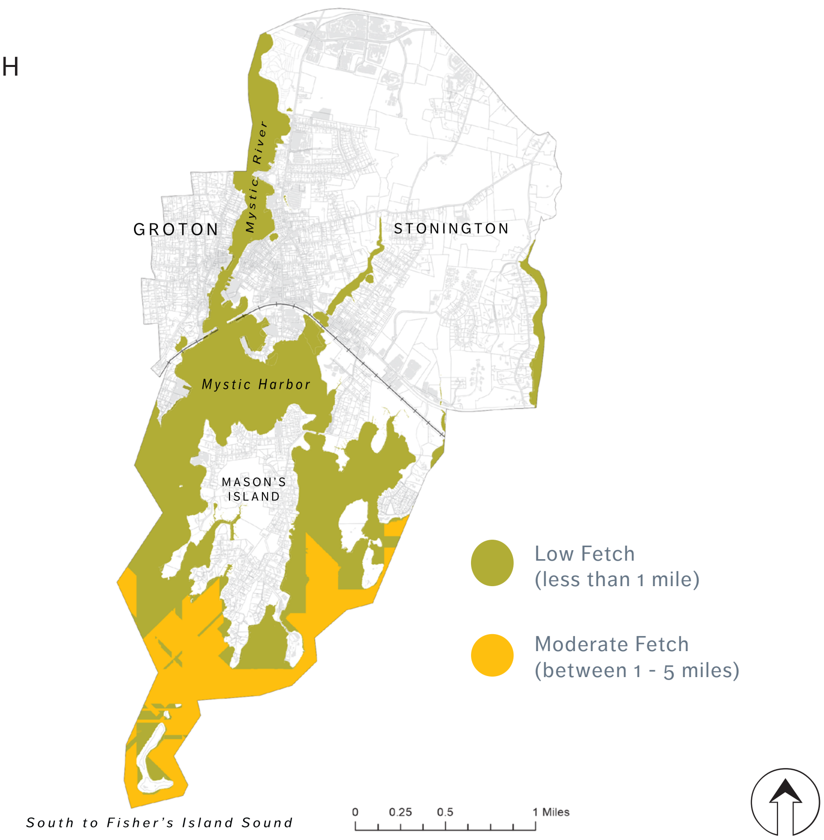
MARSH TOE/SILL

Areas with moderate fetch would require the addition of protective structures at the foot of the marsh such as a toe or sill in order to allow for marsh creation.

LIVING BREAKWATERS

Areas with high fetch are suitable for the more hybrid, structural technique of living breakwaters or a combination of living breakwaters with marsh creation on the landward side.

FETCH



FINDINGS

Shorelines in the southeast portion of the project area that are exposed to the open ocean experience a higher fetch. Mason's Island and the surrounding landforms of Groton and Latimer Point effectively protect the inner harbor, giving it a lower fetch.

IMPLICATIONS

These findings indicate that the majority of the project area has a fetch appropriate for siting marsh enhancement/creation projects, while the southeastern tips of Mason's Island, Latimer Point, and Ram's Island have higher vulnerability to natural wave energy and thereby have a more appropriate fetch for living breakwaters.

PROCESS

Based on the precedence of the "Modeling Site Suitability of Living Shoreline Design Options in Connecticut" project developed by Jason Zylberman at UCONN, fetch was used as a proxy for wind wave energy in this report (Zylberman, 2016). A GIS-based fetch model developed by David Finlayson, of the USGS Pacific Science Center, was used to run the analysis (Rohweder et Al., 2012). (A more thorough, step-by-step explanation of this process is outlined in Appendix III) This automated model evaluated the average fetch per 3 x 3 ft. area from wind directions including North, Northeast, East, Southeast, South, Southwest, and West.

ADDITIONAL CONSIDERATIONS

This analysis required several simplifications, including setting a boundary to contain Fisher's Island Sound due to current limitations of the GIS fetch model used. (See Appendix III). This analysis also represents a limited measurement of wave energy by only measuring fetch. TNC's "Living Shorelines in New England" document recommends including measurements of local current strength and wake waves created by local boat traffic in the assessment of wave energy. While Mystic Harbor is a no-wake zone, greatly reducing the potential effect of boat traffic on shoreline erosion (Allyn, 2019), field data collection is strongly recommended to determine a more thorough understanding of the energy state in areas where living shoreline strategies are proposed.

Tidal Range

Tidal range refers to the height difference between the local average high and low tides. Another way to think of it is, the vertical change in the water level experienced each day due to the tides. A low tidal range means that there is little difference between daily low and high tides, and that the local water level remains fairly consistent. Whereas, high tidal ranges mean that water levels rise and fall dramatically within the cycle of a day.

Tidal range can be a determining factor for which types of living shoreline techniques are appropriate in an area. For example, while marsh enhancement/creation projects are suitable for low to high tidal ranges, the use of sills with shellfish or living breakwaters are usually only suitable for locations with low to moderate tidal ranges. This is because areas with high tidal ranges have longer transition periods between low and high tides where water elevations are low and shellfish may be exposed to the air for too long, damaging their health (TNC, 2017). Living breakwaters using shellfish are also not suitable to areas of high tidal range for this reason. Large tidal ranges also mean that the water depths are deeper in such areas. Since living breakwaters are most effective when built to extend in height into the intertidal zone where waves are breaking, this would mean building an extremely large structure to maintain their protective function (TNC, 2017). The size of such structures is expensive and often not financially feasible.

Coastal tidal ranges depend on the underwater topography and the size of a harbor, sound, or other semi-enclosed body of water. For example, wide harbors often have relatively low tidal ranges compared to narrow-mouthed bays that may act as funnels creating higher tidal ranges. To understand this interaction, it may be helpful to envision pouring the same amount of liquid into a wide, low glass versus a narrow and tall glass. In the narrow glass there isn't room for the water to spread out and it fills up the glass to a higher level (Tide Formation). Mystic harbor, located east of Long Island Sound, has a moderate exposure to the open ocean, which contributes to the low tidal range in this region.

Tidal ranges are also not constant values, but change depending on the sun and moon's effect on the shifting tides. To simplify the measurements of tides, average values of all tides measured over a standardized period of 19 years called the National Tidal Datum Epoch are commonly used in living shoreline projects. These average high and low tide values are referred to the mean high water (MHHW) and mean low water (MLLW), and are available from local tide measuring stations. NOAA stations, such as Station 8461490 located in Mystic Harbor from which the tidal data for this project was obtained, measure tide elevations every 6 minutes, creating robust data sets with reliable averages (NOAA Datums).

TERMINOLOGY:

Mean high high water (MHHW) is the average elevation of all high tides over the standardized 19 year period referred to as the National Tidal Datum Epoch

Similarly, mean low low water (MLLW) is the average of all low tides within the National Tidal Datum Epoch.

LOW TIDAL RANGE: Less than 3 ft

MODERATE TIDAL RANGE: 3 - 9 ft

HIGH TIDAL RANGE: Greater than 9 ft

SUITABILITY:

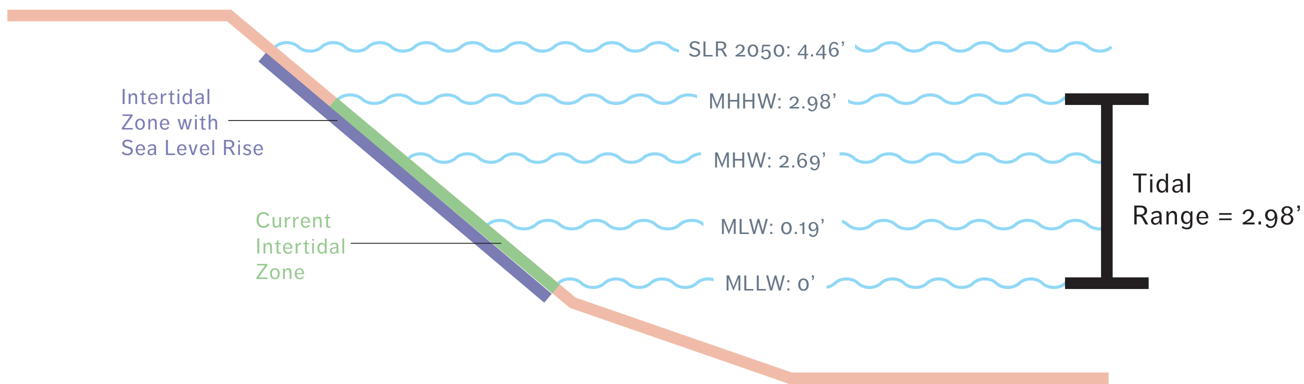
MARSH ENHANCEMENT/CREATION

Tidal range is not a significant determinant for the suitability of marsh vegetation-only projects. A range of low to high tidal ranges are appropriate.

LIVING BREAKWATERS

Living breakwaters are most suitable for areas with low to moderate tidal range.

VISUALIZING TIDAL RANGE:
CURRENT AND ADJUSTED TO INCLUDE SEA LEVEL RISE BY 2050



The graphic above shows the various elevations for the average tides as measured at the tide station in Mystic Harbor. All measurements are relative to the MLLW which is set standardized at elevation 0 feet. A sea level rise elevation has been added to visualize the potential future highest tide by adding a projection of 20 inches of sea level rise by the year 2050.

FINDINGS

Local tide measurements indicate that this region has a moderate tidal range of approximately 3 feet.

IMPLICATIONS

The moderate tidal range found within the project area is suitable for both marsh enhancement/ creation and living breakwater projects.

ADDITIONAL CONSIDERATIONS:

This method of determining tidal range is a preliminary approach to assessing the conditions for the full project area. Site-specific field data collection may be necessary for determining more precise tidal data to develop technical specifications for any living shoreline project designs.

PROCESS

The analysis process for the tidal range involved sourcing tidal datum from the nearest NOAA station and comparing the data to the ranges appropriate for each type of living shoreline technique as outlined in the matrix. Since this methodology determines one tidal range value for the future project area, no map was made to illustrate this analysis.

The following formula was used to determine the average tidal range for the project area.

MHHW - MLLW = Tidal Range

Tidal Data from NOAA station in Mystic Harbor:

MHHW = 2.98 ft
MLLW = 0 ft
MHW - MLW = **Tidal Range**
2.98 - 0 = **2.98 ft ~ 3 ft**

Tidal Zone

The tidal zone criteria determines the suitable area for a living shoreline technique in relation to the tidal range. Not all living shoreline types are suitable for all areas. For example, marsh enhancement/creation projects are only appropriate in the intertidal zone, while living breakwaters can only be sited in the intertidal or subtidal zones (TNC, 2017).

TIDAL ZONE SUITABILITY:

MARSH ENHANCEMENT/CREATION

Marsh projects should be sited in the intertidal zone only.

LIVING BREAKWATERS

Living breakwater structures can be sited in the intertidal or subtidal zones. While living breakwaters can provide more protection from storms when they are located in the subtidal zone, they can protect from everyday erosion from daily wave action when sited in the intertidal zone.

The location of tidal zones depends on both the tidal range, as explained on the previous page, and the local topography and bathymetry. These zones are categorized by their location in relation to the elevation of the local average high and low tides, and are categorized as follows:

UPLAND ZONE

Land above highest tide line (i.e. above MHHW). This area only experiences inundation by seawater from coastal storm surges

INTERTIDAL ZONE

The area between the local average highest and lowest tides (i.e. between MHHW and MLLW)

SUBTIDAL ZONE

The underwater area below the local average lowest tide (i.e. below MLLW). This area is permanently submerged.

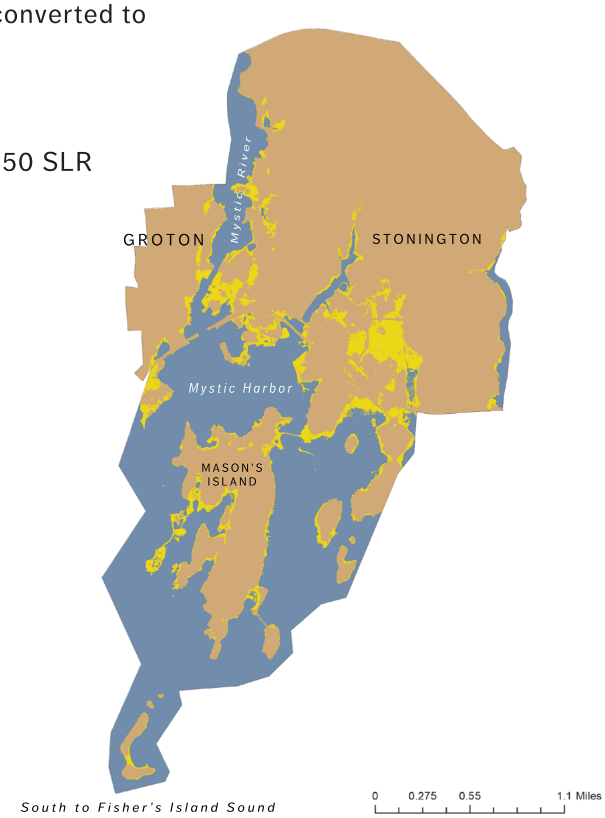
Marsh enhancement/creation projects involve the restoration or man-made creation of tidal marsh ecosystems comprising hydrophilic plants that require daily flooding. They therefore must be located in the intertidal zone where daily tidal flooding provides these plants with the appropriate habitat conditions. Water elevations within the intertidal zone also determine the average level of salinity which then determines the appropriate marsh plants for a designed living shoreline area.

The appropriate choice of location for living breakwater techniques can differ depending on the form and material of structures and the priorities for coastal protection. Oyster-based living breakwaters are most often located within the intertidal zone to mimic their natural habitat. Structures in this location can intercept low waves and thereby reduce shoreline erosion. However, this placement closer to the shore does not provide protections from storm surges with larger wave heights. Subtidal living breakwater structures such as artifical reefs, on the other hand, can help to break offshore waves, decreasing the overall wave energy reaching shore, and lowering risks from moderate storm surges (Cunniff, 2015).

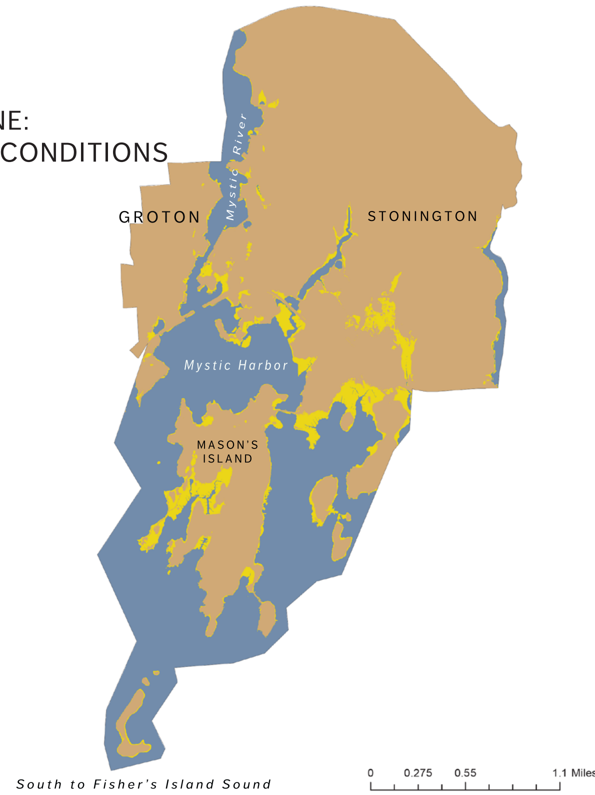
FINDINGS

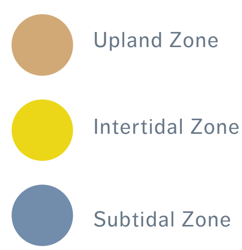
Due to the moderate tidal range experienced by the shoreline in the project area, the majority of the shoreline within the project area has a narrow band of intertidal zone. Larger areas of intertidal zone correlate with existing or historic wetlands that have been converted to development.

TIDAL ZONE: 2050 SLR



TIDAL ZONE: CURRENT CONDITIONS





IMPLICATIONS

There are many areas suitable for marsh enhancement/creation projects in the narrow intertidal zones found along most of the shoreline within the project area. Large intertidal zones may correspond to existing tidal marshes that could be ideal for enhancement or restoration projects. The relatively shallow harbor elevations and moderate tidal range result in extensive nearshore subtidal areas suitable for living breakwaters.

PROCESS

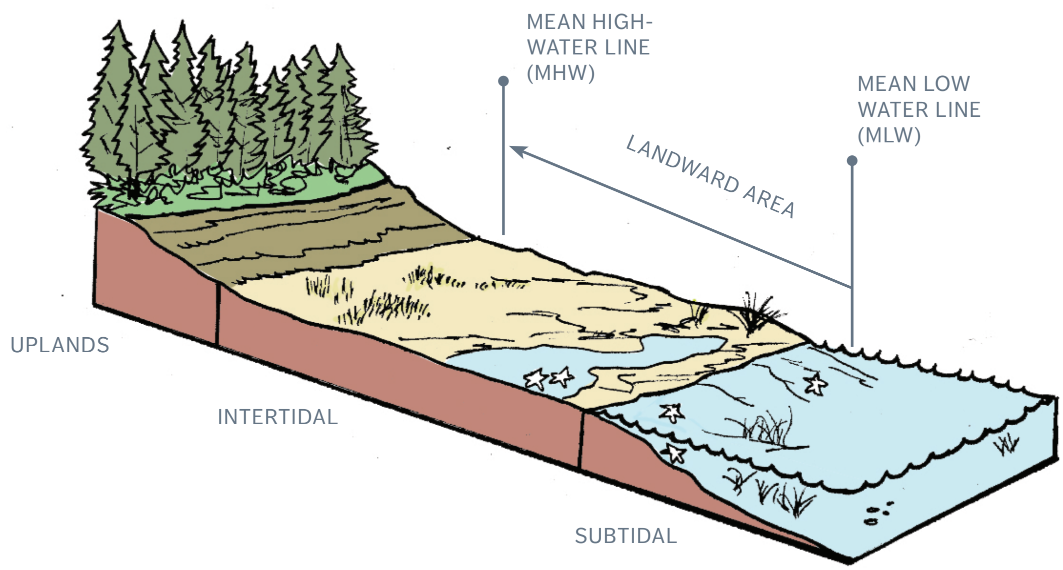
To determine the location of tidal zones, maps of combined land and underwater topography (topobathy LiDAR) were sourced from NOAA and then classified based on the elevation ranges determined by local tidal data. Based on the precedent of scientific research on the advancement process of tidal wetlands, a small emergent upland area of 0.5 meters was added to the intertidal zone to anticipate natural wetland growth and variability (Anisfeld et al., 2016). In order to anticipate potential changes in tidal zones due to sea level rise, two elevation maps were created, one illustrating the existing locations of the tidal zones and one illustrating the shifting of these tidal zones in response to the projected 20” of sea level rise by the year 2050.

Landward Slopes

The landward area begins at the Mean Low Low Water line and extends into the uplands. The steepness or the percent slope of that area is used to determine the applicability and success of each living shoreline technique.

Establishing a marsh habitat requires low or gentle landward slopes. Gradual or low slopes help to reduce incoming wave energy running up the shore and marsh plants establish faster than they would in an area with steep landward slopes where incoming waves hit the shore at high velocity, often destroying marsh species. If the landward area is moderately sloped then additional protection could be installed in the form of a "toe."

Living breakwaters can be installed in places where landward slopes range from low to steep.



FINDINGS

Low slopes dominate the entirety of Mystic's landward shoreline, while moderately sloped areas are woven throughout the landscape further upland.

IMPLICATIONS

Considering landward slope criteria alone, the establishment of marsh habitat is appropriate anywhere along the entire flat coast of Mystic, with the addition of a "toe" in moderately sloped areas to prevent incoming waves from eroding the marsh habitat.

Living breakwaters are suitable anywhere along the coast since they can be installed in landward areas with low to steep slopes.

PROCESS

Using topobathymetric information, landward slopes (area beginning at the Mean Low Low Water line and extending upland) were determined by performing a slopes analysis and the resulting slopes were then classified based on the suitable slope percentages for each living shoreline strategy outlined in the criteria applicability matrix.

LANDWARD SLOPES

Bathymetric Slopes

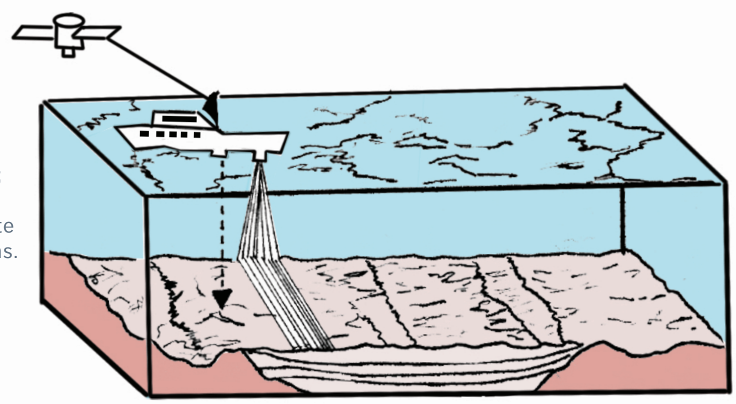
Bathymetric slope is the steepness or the percent slope of underwater terrain. The bathymetry, or underwater terrain, affects the height of waves approaching the shore. For example, steeper nearshore bathymetry allows large waves to hit the shore, while a gradual or low bathymetric slope causes incoming waves to break as they near the shore, resulting in less erosive wave energy (O'Donnell, 2015).

The steepness of Mystic's nearshore bathymetry is used to determine the applicability and success for siting each living shoreline technique.

Marsh establishment requires low to moderate underwater slopes because incoming waves will be less aggressive and erosive. This will allow for the establishment of marsh plants.

Living breakwaters can be installed in places that have nearshore bathymetric slopes ranging from low to steep.

Ocean floor topography is mapped in a variety of ways; using sonar, Lidar, or satellite imagery systems.



FINDINGS

Flat slopes characterize underwater topography within the project area.

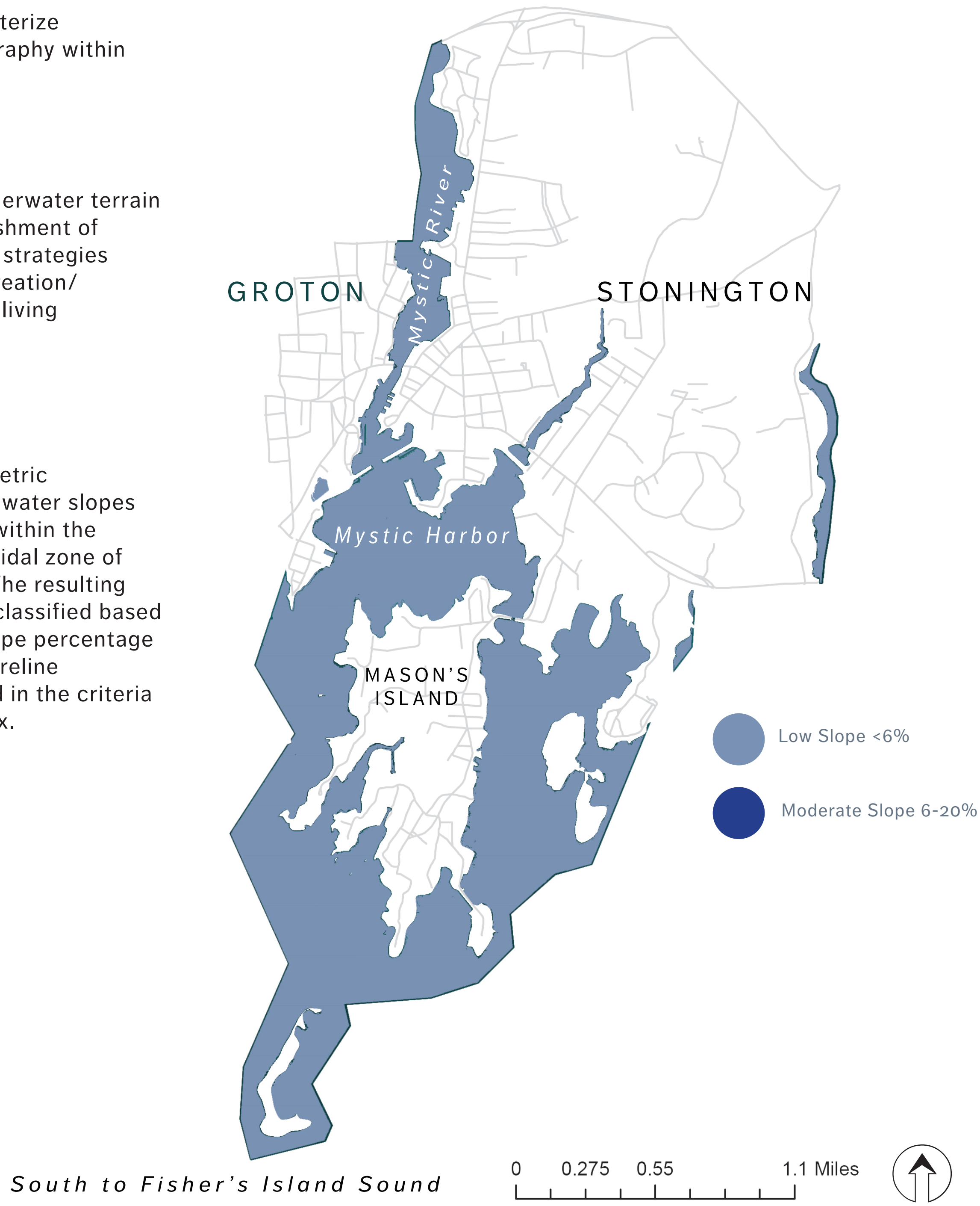
IMPLICATIONS

The area's flat underwater terrain invites the establishment of all living shoreline strategies including marsh creation/ enhancement and living breakwaters.

PROCESS

Using topobathymetric information, underwater slopes were determined within the intertidal and subtidal zone of the project area. The resulting slopes were then classified based on the suitable slope percentage for each living shoreline technique outlined in the criteria applicability matrix.

BATHYMETRIC SLOPES

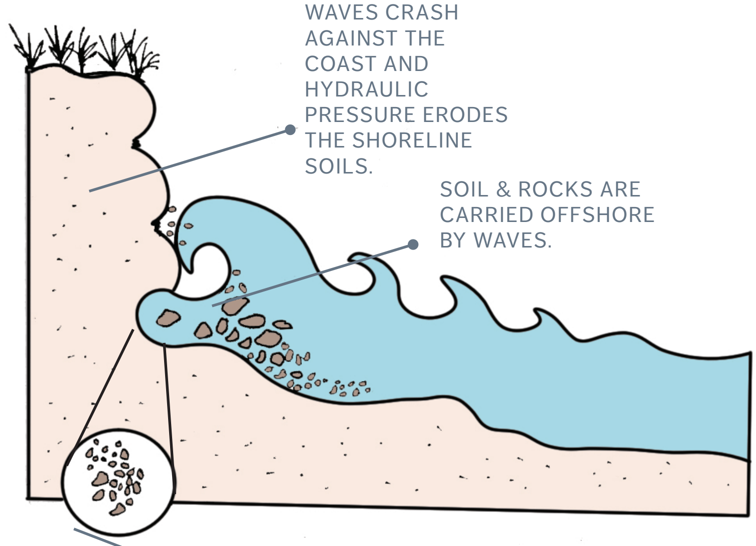


Erodibility

Erodibility refers to the intrinsic susceptibility of soil particles to detach from one another or erode by water runoff or raindrop impact. Soil erodibility depends on soil texture, permeability, structure, and content of organic matter. The higher erodibility of a soil, the greater the chances are of it eroding. Soils with a high erodibility along the coastline, if not well protected, could result in a landward retreat as a result of the cumulative effects of wave energy and stormwater runoff. These forces can cause soil particles to separate and diffuse into the ocean water.

Erosion rates measure the amount of erosion that has occurred within a specific time period and typically determines the likelihood of shoreline erosion, but insufficient data for the project area directed the use of soil erodibility as a proxy for erosion rates. Long term monitoring and measurement of erosion rates within the project area could be performed to better inform site suitability.

Marshes are best sited in areas with low to moderate soil erodibility or areas where soil is stabilized to allow marsh species to grow without being washed away by incoming waves. Living breakwaters do not require specific soil erodibility characteristics and can be sited in areas where soil erodibility ranges from low to high.



FINDINGS

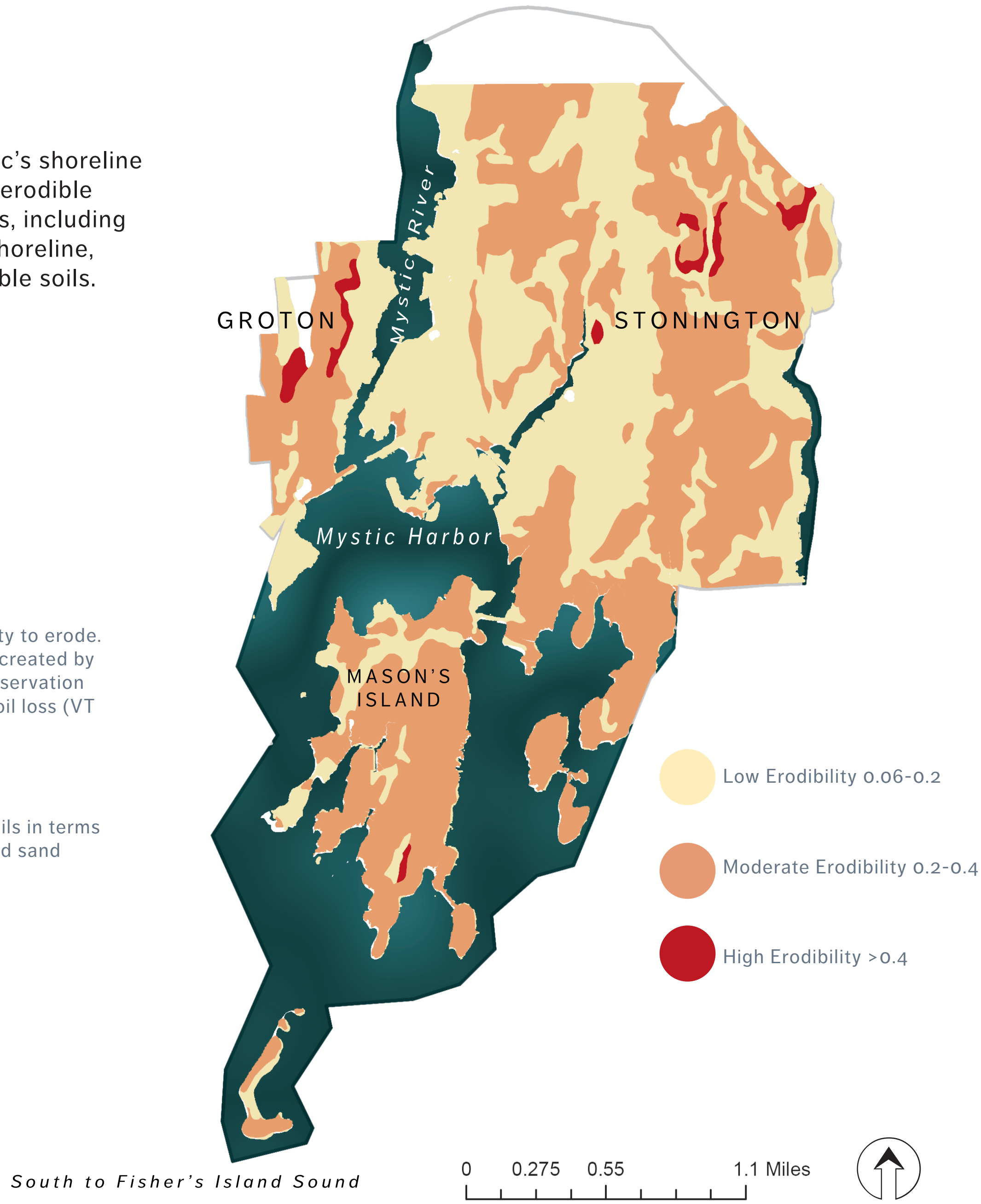
The majority of Mystic's shoreline comprises moderate erodible soils, with some areas, including downtown Mystic's shoreline, comprising low erodible soils.

K-FACTOR

Soil's intrinsic susceptibility to erode. The erodibility factor was created by The Natural Resource Conservation to be used in estimating soil loss (VT DEC).

SOIL TEXTURE

The general make up of soils in terms of the amount clay, silt, and sand particles present.



IMPLICATIONS

Mystic's entire coastline consists of soils with low to moderate erodibility and the coastline meets the erodibility requirements of marsh habitat. Living breakwaters are able to persist in areas with low to high soil erodibility, and are therefore applicable along the entire coast of Mystic.

PROCESS

A soil survey analysis was conducted, using the USDA National Resource Conservation Service soils map. This map differentiates individual soil types within the project area and the associated erodibility of each soil type. The levels of erodibility (k-factor) were classified as low, moderate, and high depending on its k-factor value (VT DEC).

Wetland Types

Mystic is situated on an estuary; freshwater flows through the Mystic River and its tributaries to the meet the saltwater of the Atlantic Ocean in the Mystic Harbor. The landscape of Mystic is dotted with both freshwater and tidal wetlands.

The National Wetlands Inventory offers a robust map for wetland identification. The National Wetlands Inventory employs a hierarchical classification system that takes into account system (marine, estuarine, riverine, lacustrine, and palustrine), sub-system (tidal, subtidal, intertidal, perennial, intermittent, limnetic, and littoral), and class, as well as modifiers of class, such as water and chemistry.

Sub-types of freshwater and tidal wetlands can be further explored by qualities like substrate and soil, site wetness, and plant community compositions (Classification of Wetlands and Deep water Habitats p. 7). The sub-types of wetlands indicate the subtle differences in the landscape and the environmental forces the wetlands are exposed to, such as wind and wave energy.

Analysis of wetlands based on system, subsystem, class, and class modifiers augments analysis of physical characteristics, such as the history of hydrological interruption by drainage interventions and the presence of certain types of vegetation.

Analysis of wetland types currently in Mystic provides contextual clues to the environmental make-up of different areas. Specifically, Mystic has three general patterns of wetlands: rocky, unconsolidated wetlands; hydrologically altered wetlands; and fragmented areas of vegetated wetlands that have phragmites present. Recommendations for living shoreline interventions that are in proximity or overlap with existing wetlands will need to take into account these conditions as they indicate potential site-specific challenges. For example, marsh-based living shoreline interventions in proximity to an existing wetland with phragmites will need to understand the potential for phragmites to spread and take precautions to prevent establishment. Additional study of on-site conditions is necessary before confirming intervention

ALTERED HYDROLOGY WETLANDS

Estuarine intertidal wetlands with irregular flooding and vegetation.

Identifies wetlands that have been altered hydrologically by drains or ditches with soils sufficient to support hydrophytes.

Occur in large swaths around Bishop's Cove, Cottrell Marsh, and Mason's Island Wetland (indicated on map) as well as smaller areas along the shores of the Mystic Harbor and Pequotsepos Brook.

ROCKY SHORELINE WETLANDS

Estuarine intertidal wetlands that flood regularly and have less than 30% coverage in vegetation.

These are high energy shoreline environments characterized by bedrock, stones, or boulders that cover 75% or more of the area.

Occur in long strips along the shores of the barrier islands around Mystic, including the south and east sides of Mason's Island.

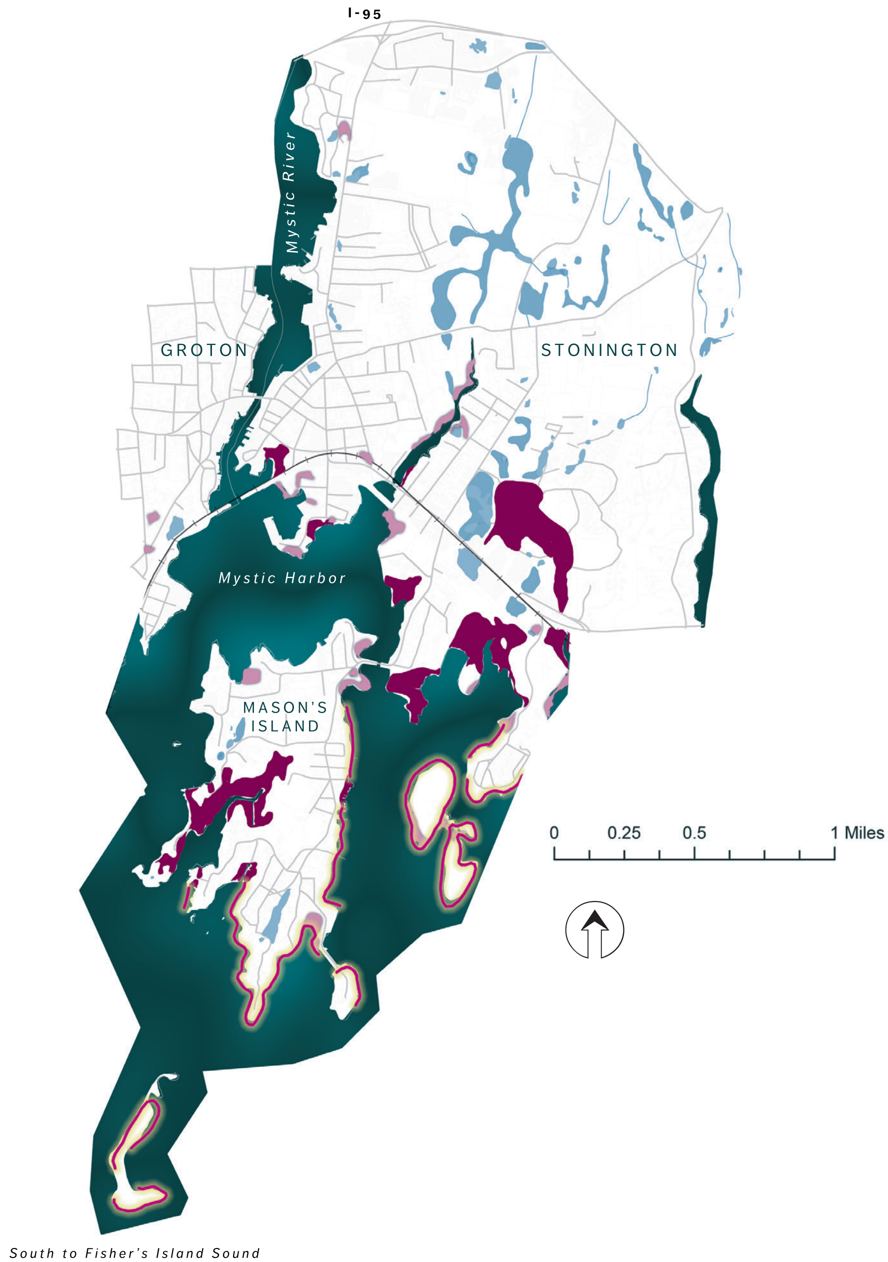
VEGETATED WETLANDS

Estuarine intertidal wetlands that range from regular (tidal) or irregular flooding with emergent vegetation.

Some of these wetlands contain common reed, Phragmites, a fast-growing, tall plant that colonizes wet soils.

Occur in small fragments along the shores of the Mystic Harbor, the Pequotsepos Brook, and the north shores of Mason's Island.

WETLAND TYPES



FRESHWATER WETLANDS

IMPLICATIONS

Wetland categories determine the viability of living shoreline interventions and implementation considerations. Hydrologically altered wetlands have costs associated with adding fill and removing drainage infrastructure, if applicable. Vegetation species selection and maintenance must take into account the presence of phragmites; invasive species monitoring and eradication can have considerable costs. Rocky shoreline wetlands indicate marsh-based interventions in the area will likely require stabilization to protect vegetation from strong wave energy; these areas are highly suitable for living breakwater interventions.

Tidal Wetland Loss

A significant reduction in wetland areas in Mystic since the 1880s is revealed by a comparison of wetland maps from the 1970s with available data on historical wetland distribution.

The trend of wetland loss in the Mystic area reflects a statewide trend. A 1990 report to Congress by the U.S. Department of Interior and U.S. Fish and Wildlife Service estimated that 74% of wetlands in the state of Connecticut were lost between 1780 and 1980. Over the span of two hundred years, the area of wetlands in Connecticut was reduced from 670,000 acres to 172,500 acres (Dahl). The reduction of wetland area may parallel an overall reduction in watershed health in the Mystic area.

The historical existence of a wetland does not necessarily mean that the location remains suitable for wetlands or can easily be restored to that condition; depending on land use history, there may be landscape-level changes to the hydrology (NWI). For instance, town infrastructure like underground sewage pipes would irreparably disrupt the soil hydrology connections.

Despite this, the historical presence of wetlands can indicate areas of regular water pooling, anticipated marsh advancement, and priorities for further suitability analysis.

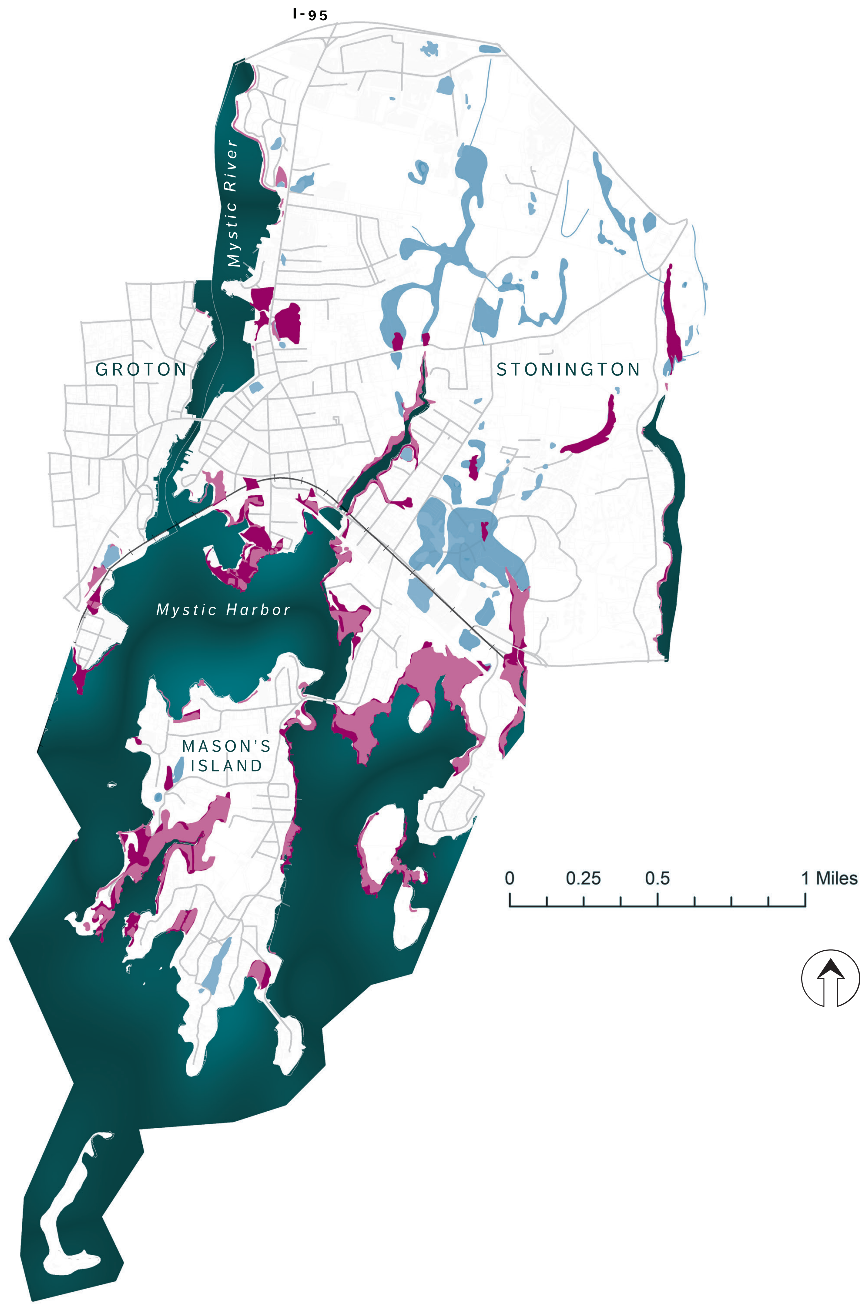
FINDINGS

The map reveals a loss of 92 acres of tidal wetlands between the 1880s and 1970s.

The map indicates two patterns of change in wetland area. Some wetland areas were completely eradicated, while others were diminished in size.

Coastal development reduced the area of tidal wetlands, confining them to smaller stretches along the shore.

In some areas, such as around Bishop's Cove (shown on map), historical wetland mapping does not account for inland, freshwater wetlands. This discrepancy reinforces the caveat that the process of map making in 1880 is unavailable so the map is suggestive, but not definitive.



South to Fisher's Island Sound

1970s Wetlands

1880s Wetlands

IMPLICATIONS

The amount of wetland loss in Mystic indicates the degree to which the built environment has disrupted natural areas. These necessary natural areas remain vulnerable to new construction.

Although not definitive, historical wetland areas will likely fit the suitability model for marsh-based living shorelines due to the physical characteristics of the site. Physical characteristics of the site, including slope, elevation, and exposure to wave energy, may remain unchanged if the land is available. However, as previously noted, investigation into the disruption of hydrology is necessary to make sure the soil is still hydrologically connected and therefore suited to be a restored wetland.

PROCESS

Topographic maps, which delineate wetlands from the 1880s and 1990s were overlaid. The total area of wetlands present in each time period was calculated and compared to determine the percent change in area.


STEAMBOAT INN
ARGIA

Coastal Structures

The Mystic coastline has been heavily altered to accommodate human access to the water. The coastline is “hardened,” transformed by engineered structures including docks and piers, bridges, groins, and riprap. Data from NOAA on coastal structures reveals that the coastline within the project area primarily consists of riprap, piers and docks, and man-made vertical slopes.

Piers and docks create access to the water and provide storage for boating activity. Riprap, groins, and revetments allow human development to extend to the very edge of the shoreline, maximizing buildable space and views of the open water.

Coastal structures manipulate the natural forces that work upon the coast—wind, waves, tides—that create a landscape in flux. Coastal structures make the shoreline more amenable to human use, but because they impede natural processes, the ecological functions of the shoreline are disturbed in the long term. Specifically, sediment allocation, hydrology, wildlife habitat, and edge diversity are impacted by coastal structures.

The existence and effects of coastal structures in Mystic may limit the location of living shoreline interventions and, if living shorelines are implemented, may challenge the viability of the intervention.

At the first community meeting, residents expressed a critical desire to maintain ease of access to the water and not impede it with coastal resilience interventions. In recognition of this desire, the analysis and recommendations in this report acknowledge the necessity of coastal structures that allow for human access, particularly by boat.

STRUCTURES ALONG THE SHORE:

IMPACTS:

A structure along the shoreline inevitably alters the flow pattern of water around it; the change in flow pattern reverberates around it. The change in flow pattern varies depending on the type of structure and the wave energy on site, but the result is almost always an increase in bed shear stress.

Shear stress is the amount of friction between a fluid and a body in its path, e.g. a groin. Bed shear stress occurs at the ocean floor, where the structure meets the bed of the water. Bed shear stress contributes to scour.

Scour is a kind of erosion caused by waves that occurs in proximity to coastal structures (OAS.org). Over time, scour threatens the stability and longevity of the structure.

DOCKS & PIERS

Docks and piers provide direct access to the water and make up the majority of coastal structures in Mystic.

Docks and piers have short-term and cumulative effects on surrounding environmental conditions, including health of vegetation and movement of sediment. Docks and piers are often constructed with chemically-treated wood; these chemical preservatives, such as chromated copper arsenate, impact the water quality of the area and viability of organisms.

Docks and piers shade out submerged and shallow-water vegetation. Docks and piers also attract more boat activity; boat activity has implications on water quality and clarity, sedimentation, and biological processes.

RIPRAP

The most common erosion intervention in Mystic, riprap consists of layers of rocks piled up to resist the erosive forces of flowing water and wave action.

Stanford's Coastal Adaptation report on Riprap acknowledges that riprap is a common intervention in part because it requires less engineering expertise to design and construct than seawalls or revetments.

Yet, riprap is susceptible to wave scouring and rock dislodgement, therefore in order to maintain function riprap requires annual maintenance (*Coastal Adaptation: Riprap*).

Living shoreline interventions often require the removal of riprap and replacement with vegetation or sand.

MODIFIED SHORELINE

The modified shoreline category includes man-made slopes and vertical walls.

Vertical walls are also referred to as revetments and bulkheads. They are retaining walls for the land, creating a 90 degree angle between

Vertical walls along estuaries are problematic because, unlike along ocean shores, beach nourishment is rarely attempted to counteract the loss of the intertidal zone. As a result, estuarine environments become 'bath-tubs,' dredged channels with steep walls, as opposed to the natural form of low, sloping edges for fringe intertidal areas (Douglass and Pickel).

BRIDGE

Two bridges cross the Mystic River: the Amtrak Bridge and the Mystic River Bascule bridge, a draw bridge.

As sea levels rise, the water of the Mystic River will have a higher mean elevation. Higher water levels result in increased wear and tear on the bridges.

The two bridges provide critical circulation routes in the region, for the train, cars, and pedestrians.

GROIN

Groins are low, wall-like structures that are installed perpendicular to the coastline, extending from land to the sea in order to trap and retain drifting sediment (Woodroffe).

Groins can have an adverse effect on the coastline by creating down drift shorelines, a phenomena that occurs when sand is trapped on one side of the groin, causing the erosion of the shoreline on the other side of the groin (The Negative Impacts of Groins).

CAUSEWAY

The Mason's Island Causeway, which connects Mason's Island with the mainland, is a raised road across low land, reinforced by riprap.

Given its low elevation, the Mason's Island Causeway is at high risk for inundation during any storm event (1%-.1%).

Improvement of resilience for the causeway is beyond the scope of this project, but living shoreline interventions in proximity to the causeway may lessen the amount of flooding and wave energy that hits the causeway.

NAVIGATION CHANNEL

The navigation channel is narrow, dredged, federally-maintained area.

FINDINGS

Coastal structures are nearly ubiquitous in Mystic; very little unmodified shoreline remains. In total, there are 137,245 feet of coastal structures within the study area.

The coastline around Cottrell Marsh is notably lacking in coastal structure modification.

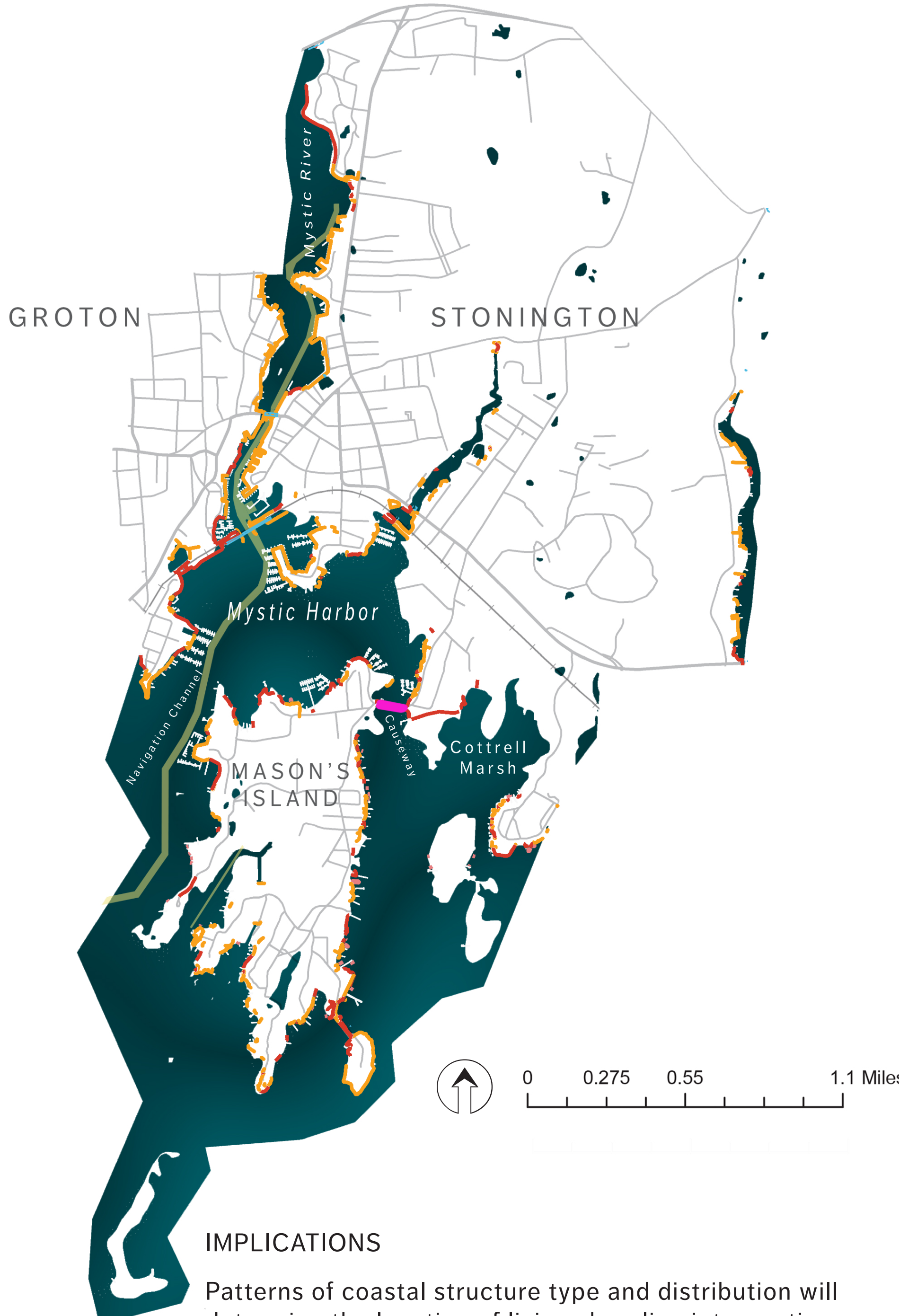
Modified shorelines make up over 42,485 feet of the coastal structure coverage area in Mystic. Modified shorelines, are most common along the Mystic River.

Riprap is the second most common alongshore structure in Mystic; approximately 27,341 feet of riprap shapes the edge where land meets water.

There are over 51,000 feet of piers and docks in Mystic. Small docks occur throughout the coastline. More substantial piers are concentrated along the banks of the Mystic Harbor. These piers directly feed into the navigation channel.

Groins are a less common coastal structure in Mystic; approximately 3,000 feet modify the shoreline.

COASTAL STRUCTURES



IMPLICATIONS

Patterns of coastal structure type and distribution will determine the location of living shoreline interventions.

Based on the strong preference in the community for boat access, recommendations for living shorelines avoid disrupting boat access structures, specifically piers and docks.

Coastal structures that are designed for erosion control, like riprap and groins, may be replaceable by living shoreline interventions that can perform the same function.

Harbor Circulation

Mystic is a historic shipbuilding town with a still-vibrant maritime culture, visible in its active harbor. Access to the coast draws people to move to and visit Mystic; local residents interact with the water for recreation and work.

Today, the Mystic River and Mystic Harbor provide multiple coastal access points. Specifically, marinas and other private docks provide year-round access to the water through mooring spaces for boats on the water and on land. At the community meeting, residents expressed a strong preference for maintaining ease of access to the water. Ease of access to the water refers to a plenitude of mooring spaces and navigable channels. Ease of coastal access is also a strong driver of the tourism industry in Mystic, which is a pillar of the town's economy.

A federally maintained navigation channel bisects the Mystic River and must maintain open; it is an area of high boat traffic with little space around it due to the width of the Mystic River. The Amtrak Bridge crosses the Mystic River as it opens to the Mystic Harbor; upstream, the Mystic Drawbridge connects the towns of Groton and Stonington. The Mystic River is an area of high boat traffic; the narrow dimensions of the river and the passage point under the Mystic Drawbridge create traffic congestion. The mouth of the Pequotsepos Brook is another area of high boat traffic as it is flanked by marinas, residential docks, and a public kayak launch.

Environmental conditions created by harbor circulation impacts the suitability and likelihood of success for both onshore and offshore living shoreline interventions. Harbor circulation disturbs water clarity and quality, shoreline form, and the composition of biological communities. Due to the shallow water location of breakwaters, this living shoreline strategy is the most affected by patterns of harbor circulation and therefore is the focus of this analysis.

Water clarity is often diminished by turbulence which increases the number of particles in the water, affects water temperature, hinders the ability of fish to find food, and diminishes the capacity of submerged aquatic vegetation to absorb sunlight. Water clarity is thus an indicator of ecosystem health (Asplund 3). In shallow waters, like the Mystic River and Mystic Harbor, boat propellers stir up sediment from the ocean floor. Propeller action decreases water clarity and, in some events, may stir up runoff nutrients, like phosphorus, that are stored in sediment and cause algal blooms.

Water quality refers to the chemical nature of the water. Human activity introduces to water bodies metals, nutrients, and hydrocarbons that alter the chemical make-up of water, such as pH and dissolved oxygen levels, and degrade its quality (Asplund 5). Harbor circulation degrades water quality through exhaust from the boat motors and related pollution, like fuel leakage (Asplund 6). Areas with high harbor circulation may have resulted in water quality that is inhospitable to certain species of shellfish and vegetation. Living shoreline interventions depend on the success of these organisms; in many cases, species like oysters can filter water and improve its chemical quality. If water has extremely high levels of pollutants, organisms associated with living shoreline interventions will be unable to establish and thrive.

Shoreline form refers to the erosion and accretion of sediment along the coastline. Boats create wakes, waves that trail boats. Wakes hitting the shoreline are a primary cause of shoreline erosion. In Mystic, the majority of the shoreline is hardened and therefore less susceptible to wake-induced erosion. However, the reverberation of wakes hitting the hard shoreline has impact on the biological composition of the nearshore environment. Because of the impact of wave reverberation on biology, living shorelines are ideally sited in areas with low-to-mid levels of boat circulation.

Harbor circulation affects biological communities including aquatic plants, fish, and other wildlife such as waterfowl, turtles, and herons. Changes in water clarity and quality affects the success of vegetation and fish nurseries. Boat propellers can disturb wildlife habitat through direct contact or noise pollution.

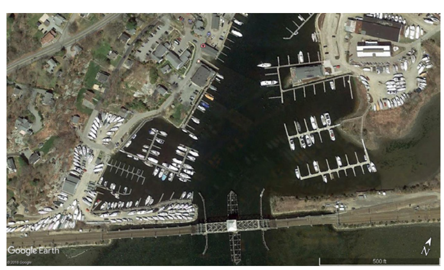
At the same time, boat circulation is a highly valued recreational and economic activity in coastal Connecticut. Mystic is a seafaring community with a long history as an active harbor. Living shoreline

INFRASTRUCTURE FOR CIRCULATION:

A byproduct of the avid boating culture in Mystic is a highly modified coastline for piers and boats.

Docks crowd the mouth of the Pequotsepos Brook.

Docks define the north end of Mason's Island.



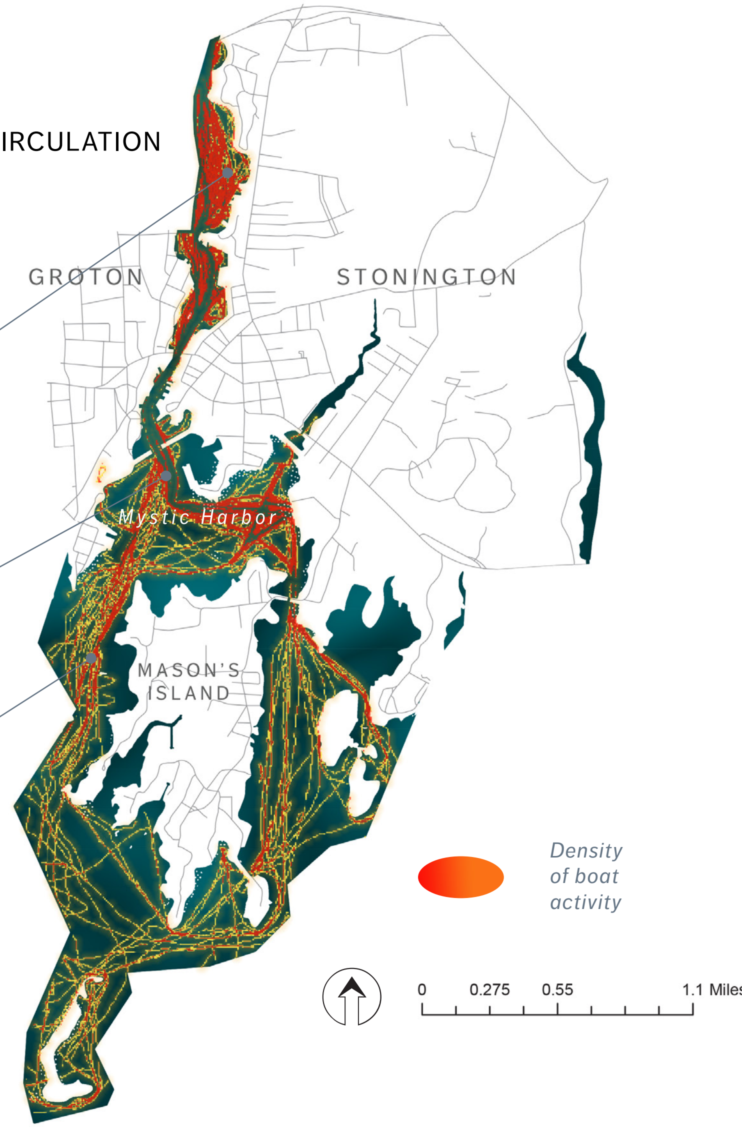
Docks and the Amtrak Bridge further con-strict the mouth of Mystic River.

Piers and docks makeup all of Mason's Point.

FINDINGS

While harbor circulation is active throughout all of the waters surrounding Mystic, it is most concentrated in the Mystic River, at the mouth of the Mystic River, and around the mouth of the Pequotsepos Brook.

HARBOR CIRCULATION



Boat activity is particularly high in the river next to the Mystic River Seaport Museum; the Museum has an active, educational seaport.

The mouths of the Mystic River and Pequotsepos Brook are areas of high boat traffic, given the concentration of marinas and docks in these areas.

A federally-maintained navigation channel runs the length of the west side of Mason's Island. The navigation channel feeds into the Fisher's Island Sound.

South to Fisher's Island Sound

IMPLICATIONS

Harbor circulation may limit the areas deemed suitable for living breakwaters. Living breakwaters are located in offshore areas, just beyond the intertidal area, which ranges from 30-100 feet depending on additional environmental conditions.

Given the semi-shallow location of living breakwaters, it's unlikely that boat activity will directly interfere with living breakwaters.

Subtidally located living breakwaters can pose a navigation hazard. Adequate signage is a potential solution to this potential hazard.

Boat activity may indirectly affect living breakwater suitability due to changes in water quality and clarity. Water testing in specific areas is recommended.


CHASER
CAPTAIN HOOK

Land Use

Understanding land use along the coast sets the foundation for understanding what is at risk, who the vulnerable stakeholders are, and how to develop community-scale strategies for coastal resilience.

The development trends in Mystic are typical of many historic New England coastal communities, with village style development built up along the water's edge over centuries of settlement. The diversity and density of the village, with historical and contemporary buildings, commercial and residential properties all intermixed along the waterfront, contribute to both the character and the heightened vulnerability of Mystic today.

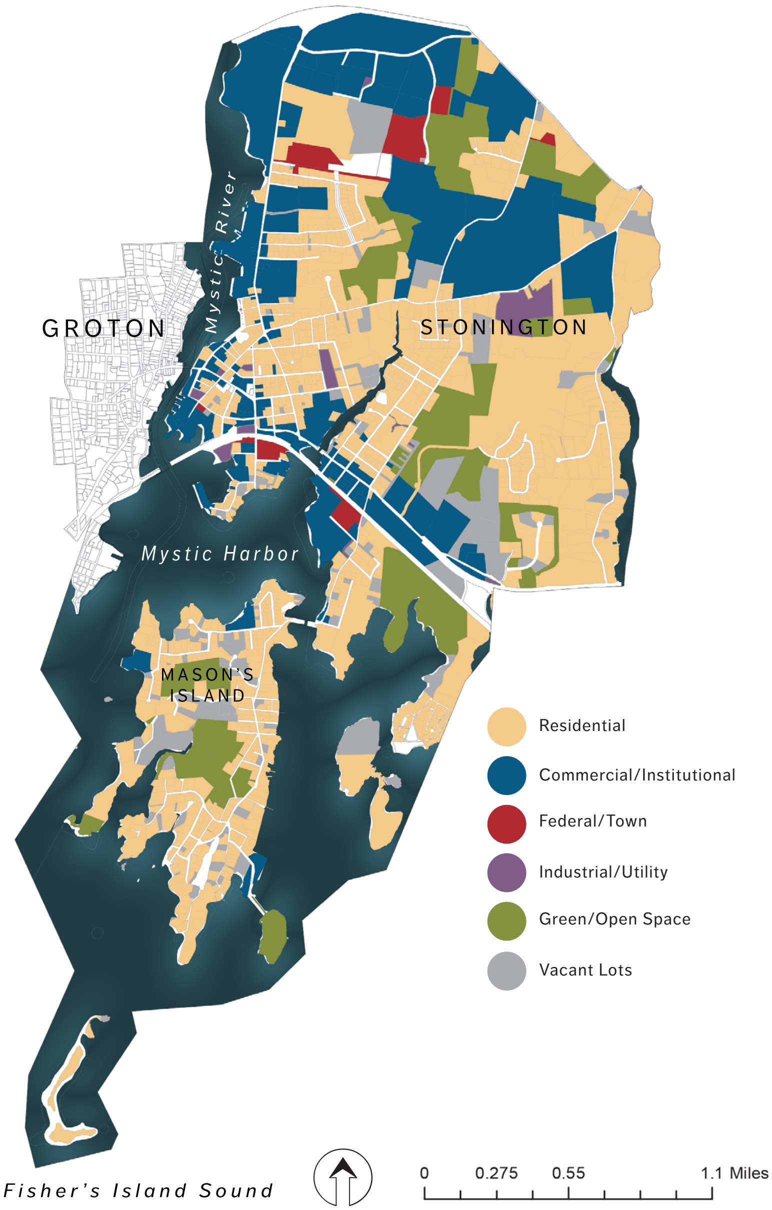
To gain insights on the major trends relevant to both increasing coastal resilience broadly and assessing the applicability of living shoreline techniques, land use was mapped for the entire project area and specifically analyzed along the shoreline.

The analysis revealed that almost all buildable land within the project area is developed, though there is the opportunity to increase the density of development north and west of the downtown area.

Residential properties represent the biggest category of land use throughout the project area and along the waterfront. The majority of this housing stock is single family housing. This trend suggests the need to design intervention strategies specifically geared towards residential waterfront property owners.

Non-residential properties represent the next highest land use, with many restaurants, shops, marinas, and non-profit community spaces congregated along the Mystic River shoreline and primary thoroughfare of Main Street to Route 1. This dense, village-style development is appreciated by locals and tourists and therefore may present unique possibilities for building greater support of coastal resilience measures in town. Siting living shoreline projects along the waterfront of commercial and institutional properties may offer increased public visibility of these projects and educational opportunities. However, designing protections for these locations also has inherent challenges due to the high density of this area.

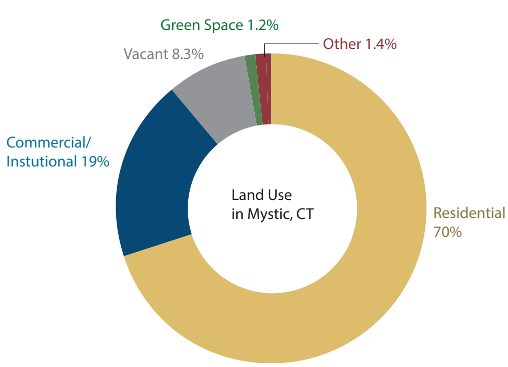
Many of the commercial properties along the Mystic River have small or zero setback requirements from the water, resulting in space constraints for marsh enhancement/creation projects (Stonington Zoning Regulations, 2018). Many of the commercial uses along the harbor waterfront are marinas, shipyards, or other water-dependent uses, as promoted by Coastal Smart Growth practice (NOAA Coastal) and supported by the town's Open Space and Development Plan (Stonington Open Space Plan, 2007). The need to preserve boat access to these locations presents design constraints for siting living breakwaters.



FINDINGS

Residential properties occupy 66% of the coastal area. Commercial/institutional properties, representing the second greatest land use, are concentrated in downtown and along the major town thoroughfare of Route 1. This effectively confines access to the waterfront to commercial and residential properties.

There are few town-owned properties along the shoreline, though there is a significant amount of undeveloped land. This undeveloped land, comprised of vacant lots, green space, and protected open space, make up 10% of parcels within the project area. The majority of the undeveloped land is made up of large protected open spaces located outside the downtown area; these may be areas readily available for living shoreline projects. Most of the vacant lots within the project area contain tidal wetlands, which would be ideal places to site marsh enhancement projects to increase the size and protective capacities of these existing ecological resource areas.



IMPLICATIONS

The organization of land use along the coast suggests the need to model intervention strategies specifically for private property owners of waterfront residences. Commercial businesses and non-profits are also important stakeholders in any plans for increasing coastal resilience in downtown Mystic. A significant amount of undeveloped land in the form of protected open spaces and vacant lots may present an additional opportunity to site living shoreline projects.

PROCESS

Land use was analyzed using GIS-based parcel data and land use codes obtained from Stonington's planning and engineering departments. Categories of land use were grouped together to offer a simplified view of development patterns.

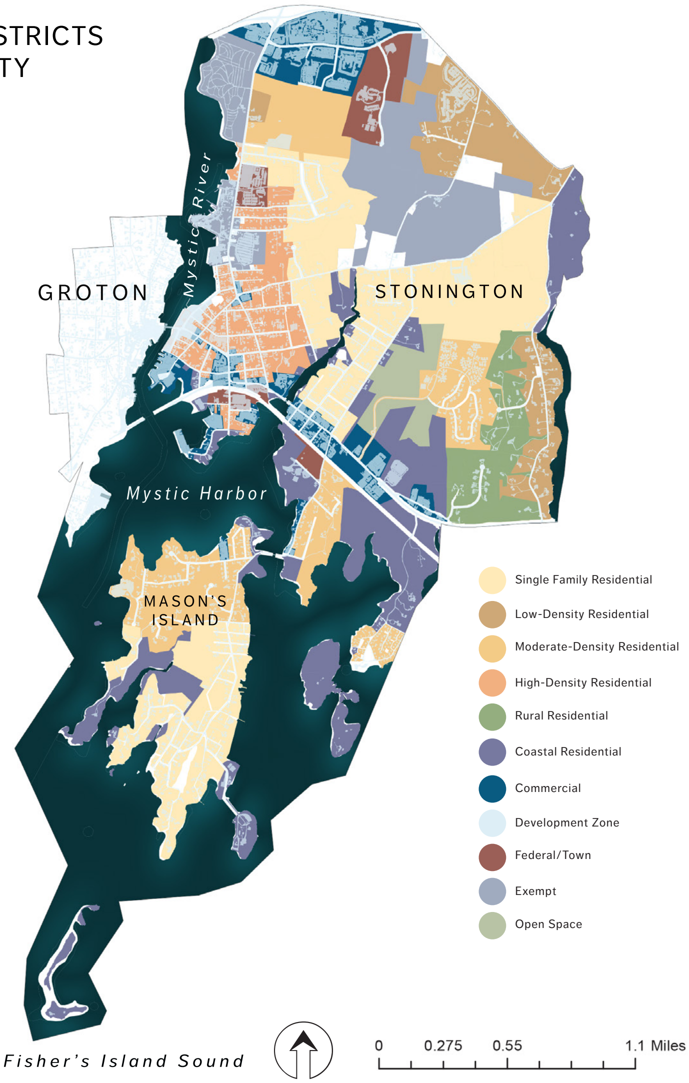
Zoning

Zoning maps dictate land use within a town and provide the regulatory framework for ecological resource protections, current resilience measures, and future development. A zoning analysis was conducted to assess how current municipal wetland protections may work to support marsh enhancement/creation projects. Current resilience measures outlined in the zoning by-laws and building code were assessed to determine how to improve planning for projected impacts of sea level rise and coastal storm surges. Density patterns were studied to evaluate how developed areas overlap with areas of high vulnerability. The focus was on finding opportunities to strengthen coastal protections and support the consideration of the projections for sea level rise into planning practices.

Current zoning reflects the historic pattern of development along the Mystic River and inner harbor. This can be seen in the concentration of commercial districts and the high-density residential zone located centrally in the downtown waterfront, and in the large moderate-density residential district on the harbor-side of Mason's Island. These areas could, according to zoning regulations, accommodate higher density development based on existing transportation and sewage infrastructure (Stonington Zoning Regulations, 2018). Similarly, according to contemporary Coastal Smart Growth practices these areas would be appropriate for future infill development (NOAA Coastal). This strategy is supported in Stonington's Open Space and Development Plan from 2015, which states sustainable development as its main priority, siting national Smart Growth principles as guiding its planning philosophy. The Plan also outlines the importance of planning for climate-related coastal hazards by restricting development in the 1% storm floodplain and preserving coastal natural resource areas for their protective abilities (Stonington Open Space Plan, 2007).

The problem is that these downtown areas of Mystic, zoned for high density development, are located within the high-vulnerability floodplains of projected major storm surges, creating a conflict between coastal hazard mitigation and smart growth practices. This conflict of interests represents a general inconsistency found throughout Coastal Smart Growth policy language today. In order to explore how resilience measures could be further incorporated into municipal planning practices to address this challenge, the current zoning regulations were

ZONING DISTRICTS AND DENSITY



FINDINGS

The zoning map of Mystic reflects historic patterns of dense development in the Downtown area along the mouth of the Mystic River and the inner harbor. However, these dense development zones sit within the 1% and 0.1% storm floodplains, meaning they are highly vulnerable to storm surges.

In terms of the zoning by-laws, Stonington has set a strong foundation for coastal resilience by establishing Coastal V and A zones with a baseline of resilience measures in building code within these vulnerable floodplain area. (See descriptions of these zones on the following page)

Municipal zoning by-laws also determine regulations of land use surrounding wetlands. These wetland protections are relevant to understanding how space for living shoreline projects and existing natural resource areas may be protected from development pressure.

Inland wetlands located in residentially zoned areas are currently protected by a 25 to 100-foot buffer, determined by review from the planning department and conservation commission. Commercial and industrial zones currently require no inland wetland buffers. While tidal wetlands, located within the intertidal zone, are within state jurisdiction, land adjacent to these coastal resource zones are within the purview of the municipality. Currently, there are no buffer requirements for areas surrounding tidal wetlands outlined by Stonington's municipal zoning regulations (Stonington Zoning Regulations, 2018).

IMPLICATIONS

Following coastal hazard mitigation planning necessitates moving development outside of the storm floodplains. In Mystic this would mean limiting new development within downtown. Current zoning regulations set a strong foundation for resilience, though many variances for new development within the floodplain reduce the effectiveness of these measures. Flexible redevelopment zones could enable new development in highly vulnerable areas and further reduce space along the shoreline for marsh projects and other coastal interventions. However, these redevelopment zones could also be re-purposed to shift growth into safer zones outside of the storm surge floodplain and areas affected by sea level rise.

PROCESS

This analysis was conducted using GIS-based parcel data and reviewing the municipal zoning regulations manual. Stonington's Open Space and Development Plan was reviewed for policy language addressing coastal resilience planning and to gain understanding of the town's vision for future growth. NOAA's Coastal Smart Growth program and Connecticut's Smart Growth principles were studied to explore how coastal resilience is incorporated into development theory for coastal communities such as Mystic today.

The following pages offer an inventory of Stonington's current coastal resilience measures, as outlined in the town's zoning regulations. All information referenced from Stonington's *Zonging Regulations Manual* (2018).

REDEVELOPMENT ZONES

Flexible redevelopment zones grant variances to new development, complicating the organization of resilience measures, while also offering potential opportunities to incentivize infill development outside the downtown floodplain areas.

One such flexible tool is the town's Floating Zoning District. According to Stonington municipal zoning regulations, the floating zone is a newly developed district that "floats" until an application is made to apply the new district to an eligible parcel. Eligibility is relative to site characteristics and application requires a master plan before site design as a way to garner community buy-in for new projects.

The flexibility of this zoning was established to facilitate mixed use development within the downtown area. This flexibility may also mean that areas currently zoned as districts with wetland buffer restrictions could be rezoned to commercial use, thus reducing wetland protections. This would result in a further loss of space for coastal protections such as living shorelines along the already highly developed coast.

However, this same floating zone could also be used to support new development patterns designed with greater resilience in mind, such as new density of development in more rural areas outside of the downtown floodplain that are currently zoned for larger lot sizes. Employinh these floating redevelopment zones could help to incentivize a transition in development practices in the future.

FLOOD HAZARD DISTRICT OVERLAY

There are several significant coastal resilience measures built into language of the Flood Hazard Overlay District.

General provisions for flood hazard reduction:

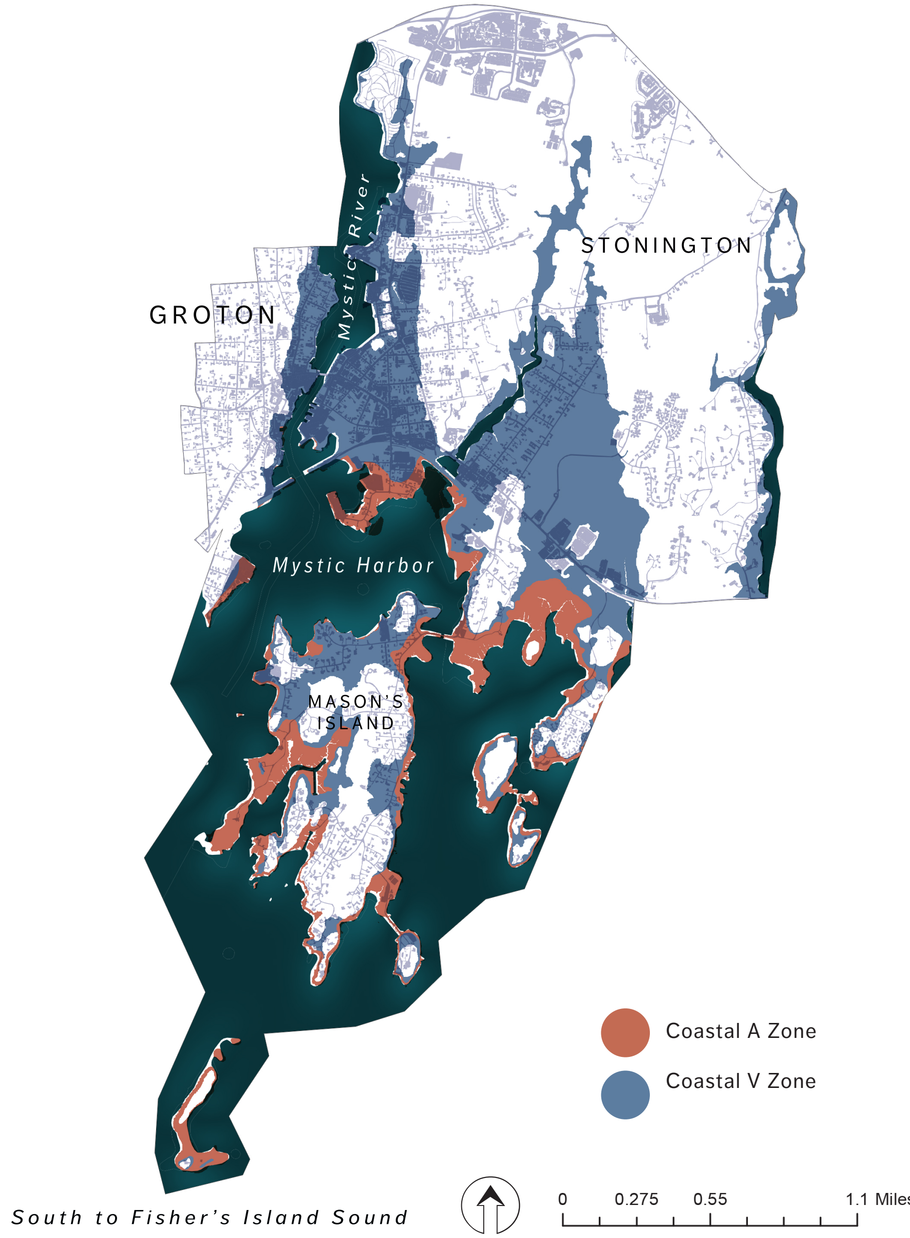
> Designation of the Flood Hazard Area (SFHA), defined as areas within the 1% storm floodplain.

> Limit the construction of buildings partially or completely over water, with exceptions made for water-dependent uses and facilities

> All new development or substantial improvements made to existing development is required to have their structural supports be built to withstand flooding depths, storm surge intensity, and wind velocities of the 1% storm.

> Within the language of the Flood Hazard Overlay District, specific building requirements are specified for new development within Coastal V and A zones accordingly. (See next page)

FEMA FLOOD ZONES



COASTAL V and A ZONES DEFINED

Coastal A and V Zones a flood zones determined by FEMA's Flood Insurance Rate Mapping Program
The Coastal V zone is the high damage zone on the immediate shoreline. This zone is determined as the area inundated by wave heights over 3 feet in height during a 1% scale storm surge.
The Coastal A zone is within the 1% scale floodplain, further inland of the V zone. The Coastal A zone is categorized as the area projected to be affected by storm surge wave heights between 3 to 1.5 feet (FEMA Design and Construction, 2005).

COASTAL A ZONE

All new development and/or substantial improvements made to existing development within the FEMA 1% Storm, Zone A, described as Special Flood Hazard Zone A and AE must comply with the following regulations:

> Residential structures are required to raise lowest elevation 2 foot above baseflood elevation.

> Non-residential structures are not required to be elevated but must have dry/water-tight floodproofing to at least one foot above the baseflood elevation.

> Elevated buildings must be designed to allow for entry and exit of floodwaters, exclude habitation spaces in their lower elevations, and prohibit utilities below baseflood elevation.

VARIANCES

Variances may be issued for the reconstruction and/or improvements of historic structures listed on the National or State Registry of Historic Places, structures on small lots half an acre or less in size, or for functional dependent coastal uses.

COASTAL V ZONE

All new development and/or substantial improvements made to existing development within the FEMA 1% Storm, Zone V, described as Coastal High Hazard Area, must comply with the following regulations:

Must be located 100 feet from the state coastal jurisdiction line, effectively providing a minimum buffer from coastal surges and inundation

> Have their lowest structural supports be elevated one foot above baseflood (i.e. one foot above the projected elevation of the 1% storm)

> The use of non-structural breakaway walls are suggested. Non-structural breakaway walls may be built below the baseflood elevation under the condition that these areas are not used for habitation. These areas are only to be used for vehicle and temporary maintenance equipment storage.

Shellfish

The waters of Mystic were once home to rich populations of shellfish including oysters, scallops, mussels, conch, lobster, crab, soft clam, and now its most abundant species, the hard clam. Mystic once relied on shellfisheries to boost and promote its economy and this industry defined Mystic as a traditional seafaring community. Historically, these shellfish resources were a crucial food source for Native American tribes and early settlers, but as human populations and development started to increase in Mystic, water quality declined which, in combination with possible over-harvesting, may have led to the decrease in shellfish diversity (Stonington Shellfish Commission, 2005). Shoreline development continues to threaten the water quality of coastal waters and the harvest of certain shellfish species is prohibited in many areas. Oysters, once prolific in their distribution, have declined in population and current GIS maps suggest the complete absence of oysters. However, the Bureau of Aquaculture states there are populations still present despite water quality issues in certain areas; shellfish remain, in lower abundance, and commercial and recreational harvesting persist.

Although the viability or success of living breakwaters and marsh habitat does not depend on the presence of shellfish, the decline and absence of shellfish suggests a need to establish living breakwaters and marsh as a strategy for enhancing shellfish populations by improving water quality and proving habitat for shellfish.

There is an opportunity for living breakwaters to expand oyster, scallop, and mussel populations. Living shorelines are a relatively new concept and currently there are no shellfish regulations that include living shorelines in Mystic, however the Bureau of Aquaculture acknowledges the benefit in developing artificial reef structures as wave attenuators and storm surge diffusers, and are considering how they might establish a harvesting or culture system with living breakwater shellfish.

Most commercial and recreational fisheries rely on the productivity of coastal marshes (Bonsack, 2016). Establishing salt marsh habitat along the coast of Mystic would supply essential nursery and feeding grounds for shellfish species, and a place of refuge during storm events.

SHELLFISH SPECIES

FINDINGS

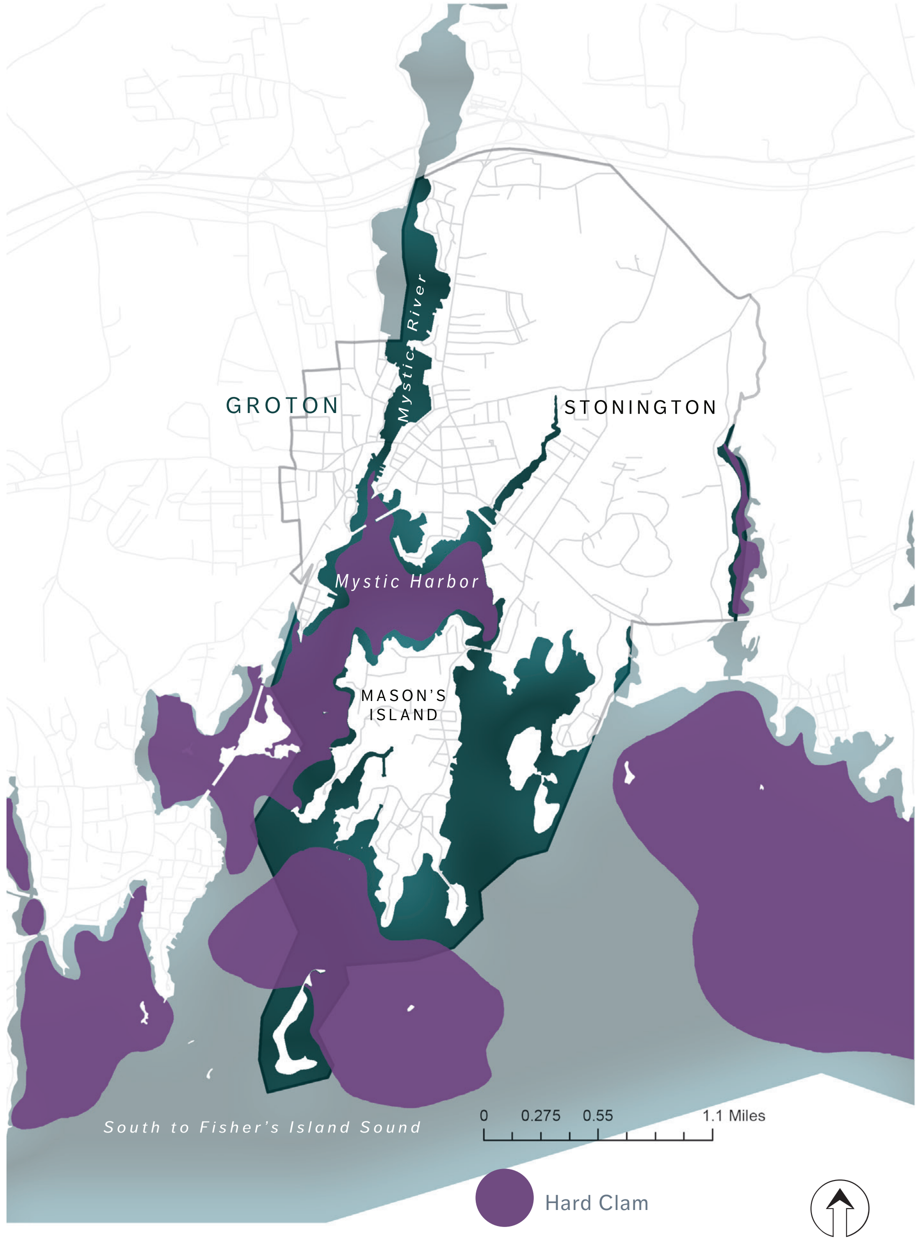
According to CT DEEP data, the only shellfish population of significance that inhabit Mystic's waters is the hard clam. Oysters, mussels, and scallops are completely absent. However, the Bureau of Aquaculture states the current GIS shellfish maps are not updated and other shellfish species are present.

IMPLICATIONS

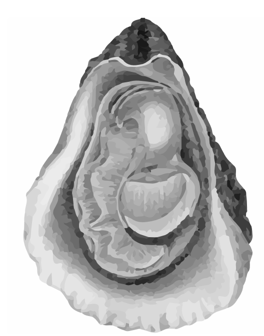
Establishing living breakwaters and seeding the structures with oyster, scallop, or mussel larvae could increase their populations. Establishing or enhancing marsh areas would create a more hospitable environment for shellfish by improving water quality and reducing the amount of sediment in the water.

PROCESS

CT DEEP provides GIS data that displays the type of shellfish present within the project area.



THE EASTERN OYSTER, *Crassostrea virginica*



Oysters are bi-valve filter feeders. They eat by pumping large quantities of water over their gills and through their cilia, and feast on algae and plankton left behind by the filtration process. One oyster can filter 50 gallons of water per day (Chesapeake Bay Foundation).

Oysters are valuable ecosystem engineers, helping to clean the waters and reduce water turbidity for submerged aquatic vegetation and other marine organisms.

Oysters attach to rocks, pilings, shells, and other substrates and are happy residing on top of one another.

Shellfish Harvest

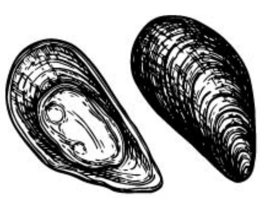
IS SHELLFISHING GOOD?

Yes, when regulated, as it is in Mystic. If the seafloor bottom is not regularly disturbed, it becomes compacted or silted over which when left untouched makes it difficult for shellfish to grow. Shellfish harvesting helps to oxygenate the lower water column and improve the quality of the sediment by loosening its inhabited silt, rock, and muck.

Underwater farming in Mystic, otherwise known as aquaculture, came into existence at a time when natural oyster harvesting was occurring at such a fast rate that it was depleting oyster populations. Mystic in the early 18th century was the first Connecticut town to establish harvesting regulations, but despite regulations, over-harvesting ensued and sparked an interest amongst oystermen to experiment with cultivation (Shellfish Resource Management Plan, 2005). Currently, there are few aquaculture operations in Mystic, partly because of the Mystic Wastewater Treatment Plant's proximity to the harbor and the Mystic River. The water surrounding the Wastewater Treatment Plant is an area of prohibition for shellfish harvest or cultivation. However, in 2015 the Wastewater Treatment Plant spent $18 million in infrastructure upgrades, which included the addition of UV radiation water cleaning capabilities, and if extensive water testing proves clean water is present, the prohibited water areas will soon be open to aquaculture operations (Benson, 2018).

Climate change and exponential human population growth have exhausted the agriculture industry to a point where people are turning to the shellfish industry to reduce pressures on the cattle industry, and the resurgence of aquaculture has significantly reduced pressures on natural fish and shellfish populations (Ecological Society of America, 2001). The Shellfish Commission believes with more aquaculture operations, the town could have a viable, sustainable food source while generating work and educational opportunities (Shellfish Resource Management Plan, 2005).

The Director of the Bureau of Aquaculture, David Carey, believes there is a potential to establish a system of commercial shellfish harvesting on the water-ward side of living breakwaters located in areas of the water deemed "approved" for commercial harvesting, and the landward side of the living breakwater could potentially allow for recreational harvest, or aquaculture purposes. The Bureau of Aquaculture would need to construct a conservation management plan with the Shellfish Commission to help protect shellfish being grown on artificial reefs.



THE BLUE MUSSEL, *Mytilus edulis*

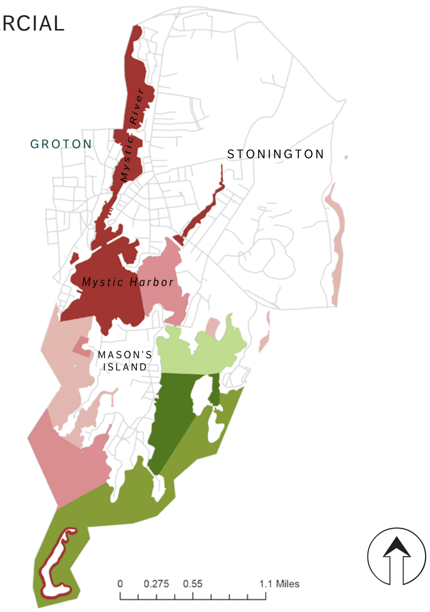
Mussels, similar to oysters, are bi-valve filter feeders that feast on microorganisms by siphoning water through their cilia, and as a result help to clean water.

The Blue Mussel has a thread-like anchor called a bysall thread that allows it to attach to rocks or other hard substrates upon which they live in dense colonies called mussel beds, while other mussel species prefer to live in marsh habitat (The Uncommon Guide to Common Life on Narragansett Bay, 1998)

SHELLFISH HARVEST REGULATIONS

RECREATIONAL

COMMERCIAL



APPROVED: Acceptable to harvest for recreational, commercial, and direct consumption.

CONDITIONALLY APPROVED SEASONAL: Generally open for harvest but with a seasonal condition, usually oriented around boating season. Closed for harvest when boat use is extremely high and gas/pollutants threaten shellfish health.

RESTRICTED-RELAY: Harvest can occur, but shellfish must be brought to open areas (approved or conditionally approved) for a period of at least 2 weeks when water temperatures are above 50 degrees Fahrenheit to be purified; requires special licensing.

CONDITIONALLY APPROVED: Generally open for harvest; closed during certain time periods related to environmental triggers, like rainfall events that increase the water's pollutant levels from runoff.

PROHIBITED: Closed for harvest at all times either due to the presence of environmental conditions that pose a health risk or due to insufficient data, however, licensed aquaculture may occur.

CONDITIONALLY RESTRICTED-RELAY: Harvest can occur when the area is deemed open; shellfish must be brought to open areas (approved or conditionally approved) for a period of at least 2 weeks when water temperatures are above 50 degrees Fahrenheit to be purified); does not require special licensing.

FINDINGS

Areas where recreational and commercial shellfish harvest is approved for direct consumption is limited to the east of Mason's Island. Restricted commercial harvesting is located to the west of Mason's Island and commercial harvesting is prohibited in the Mystic River and Mystic Harbor, an area where there is high boat traffic and poor water quality.

IMPLICATIONS

Shellfish grown on living breakwaters could be integrated into recreational and commercial beds within all classification areas except prohibited areas.

PROCESS

The Bureau of Aquaculture provides GIS data displaying recreational and commercial shellfishing areas based on their classifications.

Water Quality

Mystic's estuary has been dealing with polluted waters since the colonial times, and while the establishment of sanitary sewers in the 1970s marked significant improvements, water pollution remains a problem as development along the coast persists (Stonington Harbor Management Plan, 1995). Water quality refers to its chemical, biological, and physical characteristics that are heavily influenced and degraded by contaminants and pollution (Perlman, 2018). Water impairment in Mystic is directly associated and impacted by three major sources: nutrient runoff, boat activity, and rising ocean temperatures.

During a rain event, water flows across the landscape and through the city where it picks up various pollutants like oil, gas, pesticides, or other organic compounds that are flushed into the sea. The shoreline functions as a point of separation between Mystic's inland and the sea, but as the shoreline becomes more developed and impervious surfaces replace vegetation, there are fewer spaces for water filtration to occur before it is conveyed into the sea. Establishing marsh habitat along the shoreline works to intercept nutrient runoff and provides an opportunity for plants to filter out nutrients and pollutants.

Boat activity within Mystic is crucial to the lifestyle of its community members, but poses many threats to water quality due to exhaust from boats, fuel leakage, and motors that generate more turbulent water that may induce shoreline erosion. Living breakwaters could help prevent wake-induced erosion, while marsh habitat could help to stabilize soil and filter out pollutants from boat leakage.

Climate change has warmed ocean temperatures about 1.5 degrees Fahrenheit since 1901 (Bradford, 2016). As sea temperatures rise, the ability for water to absorb oxygen is reduced and aquatic life becomes more vulnerable to pollution from runoff or boats. In other words, as water temperatures increase oxygen that supports aquatic organisms decreases (EPA, 2017). Rising sea temperatures threaten the health of shellfish, and further research may be needed to ensure the health of shellfish grown from seeded living breakwaters will not pose harmful risk to other aquatic species or humans if consumed. Increasing vegetation like marsh grass, sequesters carbon, and works to mitigate the major driver of rising sea temperatures, climate change.

FINDINGS

Water to the east and south of Mason's Island does not meet Connecticut's Water Quality Standards and is deemed to be impaired. CT DEEP suggests water quality standards to the east and south of Mason's Island and the Mystic River are not up to standards to support shellfish consumption. The Mystic Harbor consists of clean water that fully supports shellfish consumption.

IMPLICATIONS

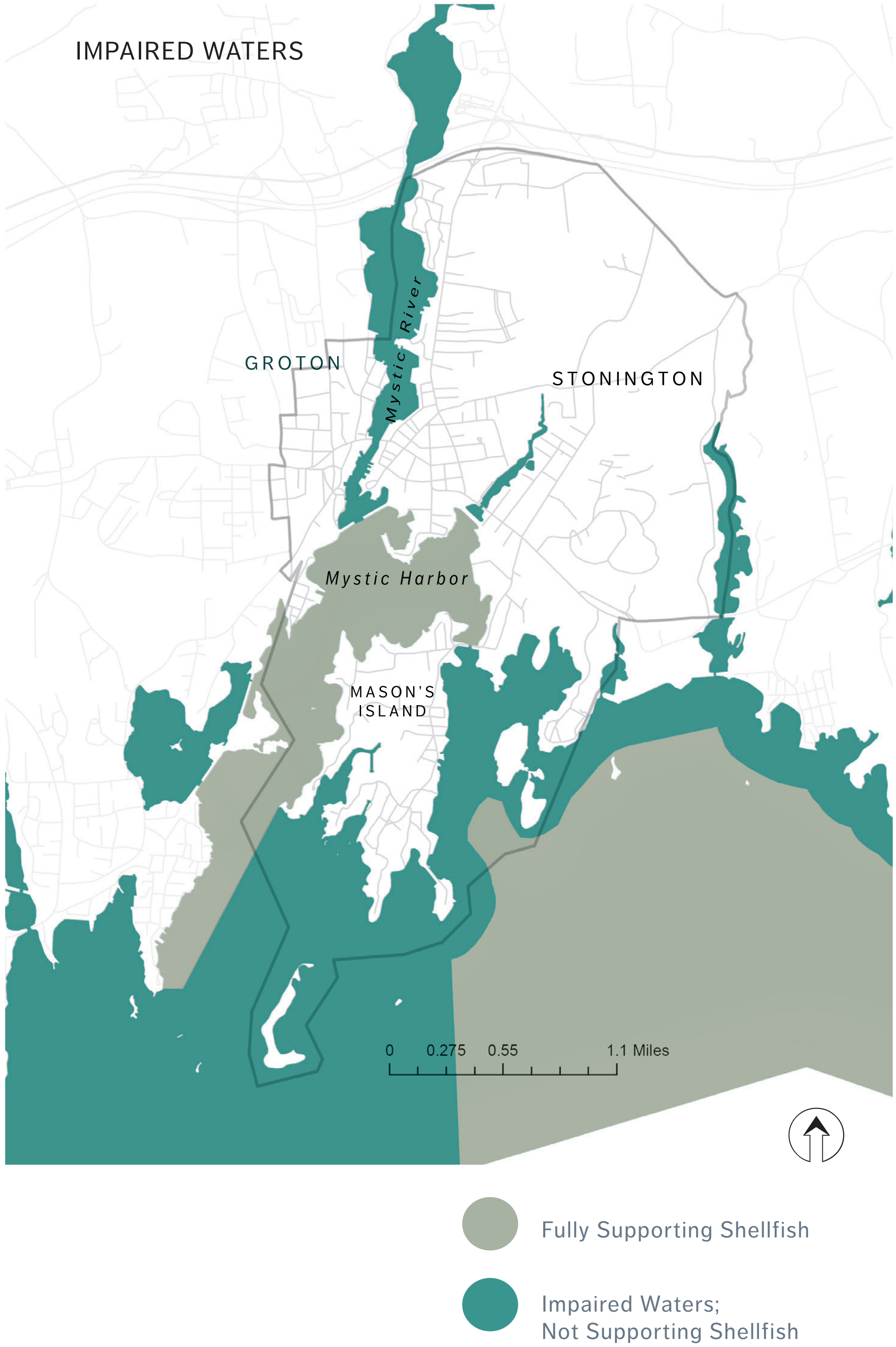
If living breakwaters were implemented along the Mystic Harbor's shoreline, the shellfish could be consumed, but if living breakwaters were established along the east and south of Mason's Island or within the Mystic River, shellfish may be toxic.

Establishing living breakwaters and marsh habitat in areas with impaired water could help to improve the health of these waters and create a fully supporting shellfishing industry. Research and monitoring of shellfish should be conducted to ensure shellfish populations are healthy as water temperatures continue to rise.

PROCESS

CT DEEP provides 2016 GIS data displaying areas where impaired water quality standards do not comply with the Clean Water Act standards and do not support the consumption of shellfish. Areas where water quality is healthy enough to support shellfish consumption.

IMPAIRED WATERS



Community Input

On January 23, 2019, students from the Coastal Resilience Team held a community meeting in Mystic Village. About 50 members of the community gathered to discuss planning for coastal resilience.

Through a series of interactive mapping activities, the Coastal Resilience Team heard feedback about areas considered the most vulnerable to storm events and assets deemed important by the community.

Community members shared their experiences of Mystic, which ranged from information about nuisance flooding, concerns about invasive species, and insight on what coastal resilience might look like. Specifically, activities asked attendees to rate their preferences for different living shoreline techniques. In addition, a survey asked attendees to consider how they envision the future of Mystic and to list their chief concerns.

The meeting brought together a diverse group of people of different ages with a variety of professional backgrounds, experiences, and interests. Given the diversity of attendees, there was also a diversity of feedback.

Written feedback from questionnaire expressed a range of perspectives on the urgency of coastal resilience implementation. A group of attendees expressed a desire for Mystic to stay the same, while another group of attendees used strong, active language to describe their vision for Mystic's coastal resilience implementation.

Approximately 50 community members attended the first meeting on January 23, 2019.

FEEDBACK

Attendees of the community meeting filled out a questionnaire. The questions sought insight on resident's priorities for Mystic and the perceived implications of climate change.

What do you think are the areas in need of urgent intervention?

Protect downtown from nuisance flooding & storm surge. If Downtown is not protected, Mystic is gone

What do you see as the easiest first step?

Get organized with strong leadership

What is your long range vision for Mystic?

As is but safe from water

How do the potential impacts of climate change affect your vision?

Need to change zoning to allow for green areas to have self propelled campers or floating houses

How do you currently interact with the shoreline? How do you want to interact with the shoreline?

Live on water Pay ≅ $5,000 / year for flood insurance

“As is but safe from water.”

What do you think are the areas in need of urgent intervention?

East Main Street floods in heavy rains now—hard to drain at high tide!

What do you see as the easiest first step? Repair the infrastructure so that valves allow water to drain back into the river!

What is your long range vision for Mystic? Current/near-future plans include significant dense construction south of the drawbridge—more impervious surfaces & multi-story buildings—seems unwise to permit!

How do the potential impacts of climate change affect your vision?

I think we're allowing unwise density in the areas closest to the river and the sound!

How do you currently interact with the shoreline? How do you want to interact with the shoreline? I walk the beaches.

Also live on Long Pond seasonally—an inland waterway that empties eventually into the Mystic River.

“I walk the beaches.”

What do you think are the areas in need of urgent intervention?

Wastewater treatment plant
Train station

What do you see as the easiest first step?

permeable pavers, asphalt
wetlands stabilization

What is your long range vision for Mystic?

Freeze new construction on flood prone land
raise causeway on Masons Is Road

How do the potential impacts of climate change affect your vision?

Concerned about increasing construction in low-lying areas

How do you currently interact with the shoreline? How do you want to interact with the shoreline?

live on an island; we have erosion during storms that have moved further inland

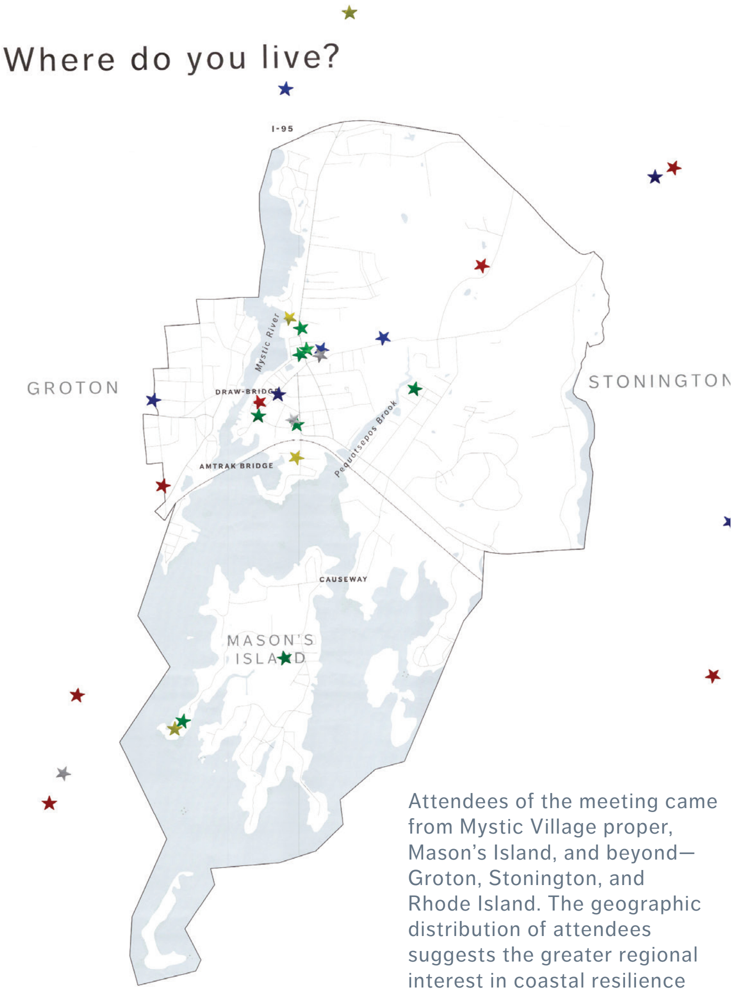
“Freeze new construction on flood prone land.”

A second community meeting was held on March 12, 2019 at the Mystic Seaport Museum. The meeting was an opportunity for the Conway Coastal Resilience Team to share draft concepts and designs for inland and shoreline strategies with community members.

Approximately 30 individuals attended the meeting. After listening to a presentation on draft recommendations, individuals were asked to reflect on what they perceived as the primary challenges if the recommendations were to be implemented. Groups of individuals came together to discuss perceived challenges and brainstorm potential solutions to the perceived challenges. The meeting provided an opportunity for community members to consider Mystic's future.

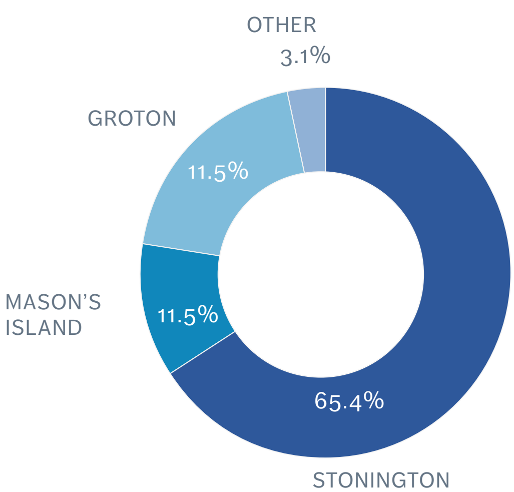
Community members were eager to share their opinions, and many of the strategies outlined in this document are a product of community member's voices.

Where do you live?

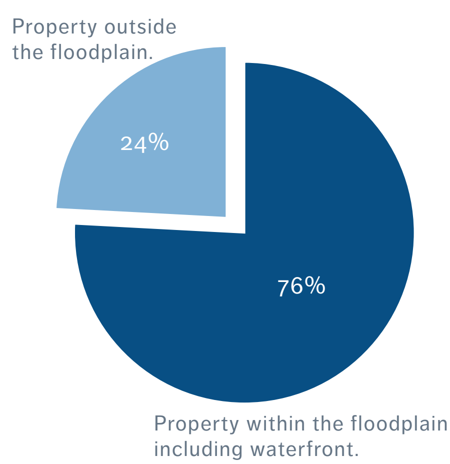


Attendees of the meeting came from Mystic Village proper, Mason's Island, and beyond—Groton, Stonington, and Rhode Island. The geographic distribution of attendees suggests the greater regional interest in coastal resilience planning.

The majority of attendees live in the town of Stonington.



The majority of attendees live in waterfront property or within the floodplain zone.



When asked what would inspire or incentivize property owners or commercial property owners to implement green infrastructure almost all agreed that an economic incentive would motivate them to take action.

They suggested this incentive take the form of lower property taxes, lower flood insurance rates, real estate tax credit, or reduced permit fees. Some believe receiving accessible green infrastructure education would motivate them to take action.

CHALLENGES

- Regulation – FEMA, zoning for homes. → state, local, Fish + Wildlife
- Not-one-size-fits-all what properties have highest wave energy?
- Salt marsh accretion is not fast enough. → add clean dredge, buy time
- Lower Church St. → inflow pipe issue
- Streetscapes maintenance
- Tree planting → viewshed
- Living Shoreline – drowned by S.L.R.
- *Permitting Process – $, time
- *condo-complex – collab. necessary.
- cost of topographic survey

The final portion of the community meeting was spent in a room-wide discussion. Representatives from each table shared their chief concerns and suggestions for solutions. The challenges that were repeatedly shared during this discussion included regulatory hurdles and the permit process, cost of implementation and maintenance, and cultural challenges like collaboration between neighborhoods and a change in the community's aesthetic.

SOLUTIONS

- MOVE / CHANGE REGULATIONS
- FURTHER ANALYSIS – SITE SPEC. Res properties to encourage Living shoreline interventions
- Education – Signage: implementation on properties – Encourage (Res) one Another.
- Help marshes migrate INLAND (to keep up w/ sea level rise)
- REPAIR OUTFALL VALVES – (FUNDING)
- Civic Groups, Garden Clubs – Small demo projects
- Communication – Help w/ Regulations process
- ~~Permit Process is~~

EDUCATING GENERAL PUBLIC – MOTHER NATURE VS. HUMAN DEVELOPMENT DEMANDS

FOCUS ON NEIGHBORHOODS COMMUNITY
↳ Each Neighb. Has diff motivations. All in this together

REARRANGE ROADS – ADD GI AT that time.

TOWN – Not pit Neighborhoods against eachother

TAILOR TO COMMUNITY.

Summary of Marsh Suitability Model

This section combines findings from previous analyses of shoreline criteria and environmental conditions in order to determine the suitability of marsh-based interventions within the project area.

DEFINING MARSH ENHANCEMENT AND CREATION

Marsh enhancement and creation are vegetation-based living shoreline interventions that mimic the coastal resilience and ecological services of tidal marsh wetlands.

Tidal marshes are wetland ecosystems located between the high and low tide levels. Subject to daily flooding, tidal marshes are zones of high biodiversity that sequester carbon, filter pollutants from water, and offer coastal resilience through attenuation of wave action and retention of flood waters.

Marsh enhancement and creation involves the planting of marsh grass along the shoreline's intertidal zone.

Improved and new marsh landscapes function to soften the velocity of waves as they approach the shore, thereby lessening the damage of storm events.

CRITERIA FOR MARSH ENHANCEMENT AND CREATION SUITABILITY

Shoreline criteria describe the physical characteristics of the landscape and are one determinant of marsh suitability.

Marshes require the following shoreline criteria:

> Marshes are suited to *low wave energy, sheltered shoreline environments with low landward and underwater slopes*

> Marshes are suitable in areas of *low to moderate erodability*

> Marshes must be sited in the *intertidal zone; a wide intertidal zone with gentle slopes is ideal*

In addition to shoreline criteria, the most relevant **environmental conditions** include:

> Existing Wetlands

> Current Land Use

> Storm Surge Patterns

A Shoreline Criteria Model to Determine Marsh Suitability:

The shoreline criteria in the project area were measured and computed in GIS to identify sites that meet the physical requirements for marsh suitability.

The shoreline criteria measured included:

- Tidal Range
- Tidal Zone
- Fetch (Wave Energy)
- Landward Slopes
- Erodibility

The resultant GIS model for marsh suitability was refined by augmenting existing tidal data to account for a projected sea level rise of 20" by 2050.

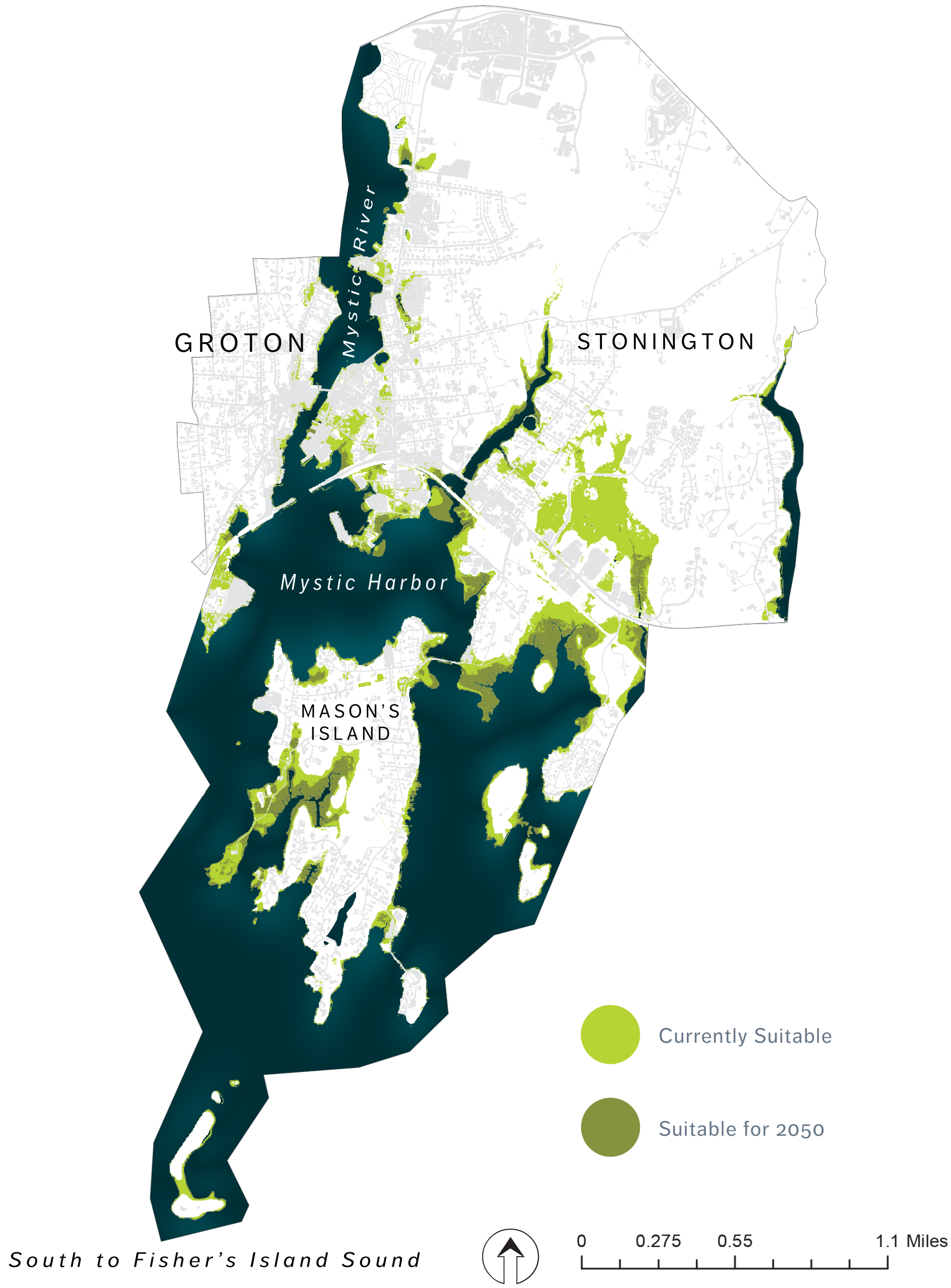
The outcome of these two models was suitable marsh habitat **currently** and in the **near-future**. Both current and near-future results meet the shoreline criteria for marsh enhancement and creation, meaning that the sites possess a physical landscape well-suited to marshes. The result of the model was categorized as being *currently suitable* and suitable for 2050.

Results for the Project Area:

The model indicates significant opportunities to enhance or create marsh since most of the project area consists of suitable low landward slopes and low wave energy environments.

The relationship between the areas currently suitable for marsh habitat and the areas suitable in 2050 suggests a pattern of potential marsh advancement in response to sea level rise. Areas of future marsh suitability are shown to extend further inland from areas of current marsh suitability.

MARSH SUITABILITY
MODEL RESULTS



Environmental conditions that further informed research into the suitability of marsh enhancement and creation included:

- Existing Wetlands
- Current Land Use
- Storm Surge Patterns

Existing wetlands indicate land and environmental conditions that are hospitable to marshes. Additionally, hydrological connections can be made between existing wetlands and new marshes, strengthening the overall health of Mystic's network of wetlands.

Storm surge intensity was gauged through a map of the flood levels for the current 1% storm; the areas with the deepest inundation levels were deemed as the most vulnerable to storm surges. The most vulnerable areas were overlaid on the GIS model map to determine high priority areas for creating marsh creating/ enhancing marsh.

Land use patterns were assessed by identifying parcels that intersect with outputs of the marsh model. Intersecting land parcels were classified by land use type: residential, non-residential, and vacant/ unbuildable.

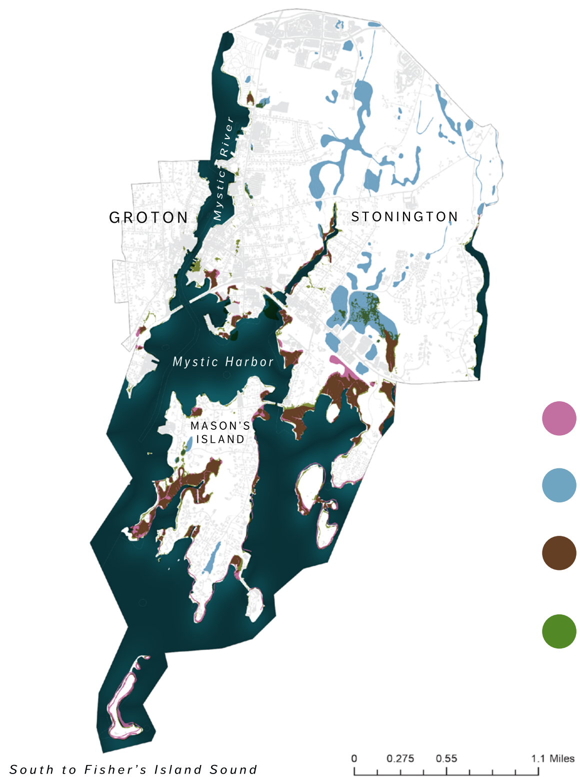
Results for the Project Area:

The analysis revealed that the current suitable areas for marsh habitat correlate with areas of existing wetlands. The relationship between the current and future marsh suitable areas suggests the potential for tidal marshes to advance into lowland areas that are currently occupied by existing inland freshwater wetlands. This connection between tidal and freshwater wetlands as a trajectory for marsh advancement suggests the importance of ensuring the protection of these resource areas and maintaining hydrological connections.

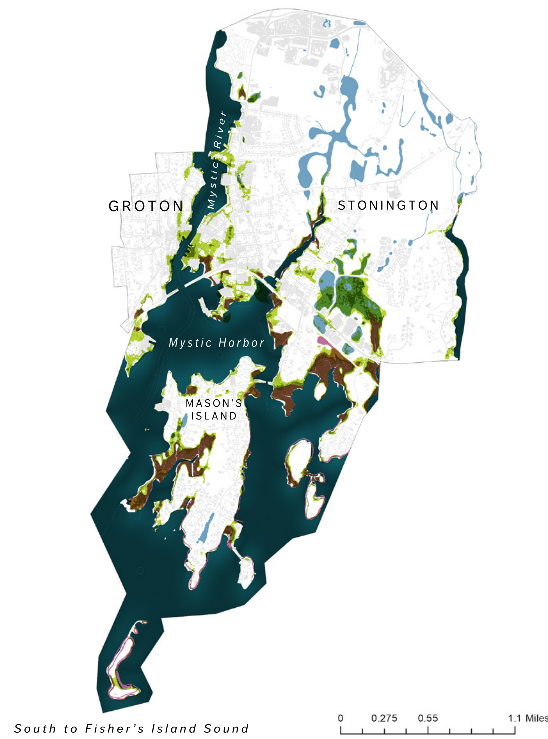
The intersection of the marsh model outputs with classified land use indicates opportunities in areas of undeveloped land and potential conflict in areas with residential and commercial development. Proposing the establishment or enhancement of marsh habitat in these different areas of land use may align or conflict with development patterns.

The land use analysis revealed that 56% of the parcels intersecting with the marsh model are residential parcels, indicating collaboration with private landowners will be necessary for implementation. 19% of the intersecting parcels are commercial and institutional properties, suggesting that working with these private landowners is also critical. These spaces occupy larger lots along the waterfront that may offer opportunities to site larger-scale living shoreline projects with educational components and higher public visibility. 12% of the parcels are undeveloped land, composed of protected open space and vacant lots. These parcels could be considered immediate opportunity areas for establishing marsh.

AREAS OF CURRENT MARSH SUITABILITY: CORRELATION TO TIDAL WETLANDS



AREAS OF FUTURE MARSH SUITABILITY EXPANSION INTO INLAND WETLANDS



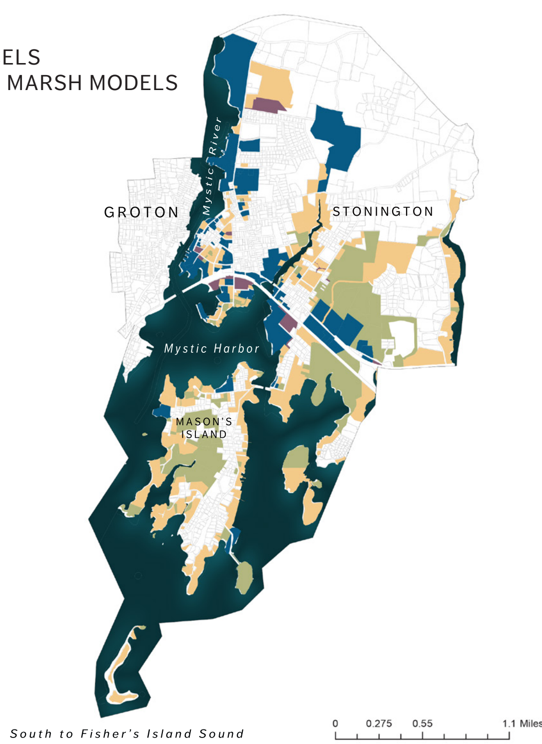
Tidal Wetlands

Inland Wetlands

Suitability Model

Suitability Model

LAND USE OF PARCELS INTERSECTING THE MARSH MODELS



56% Residential

19% Commercial/Institutional

10% Undeveloped Land

Summary of Living Breakwater Suitability Model

This section combines findings from previous analyses on shoreline characteristics and environmental conditions in order to determine the suitability of living breakwaters within the project area.

DEFINING LIVING BREAKWATERS

Living breakwaters are a hybrid living shoreline intervention that creates shallow-water landscapes and provides coastal resilience and ecological services.

Living breakwaters use a hard structure, such as a concrete dome, to provide scaffolding for life. Bivalves, like oysters and mussels, and vegetation anchor onto the hard structure which provides a new habitat area. Sediment builds up on the landward side of the breakwater, decreasing water depth.

The new shallow-water landscape functions to down-shift the velocity of waves as they approach the shore, thereby lessening the damage of storm events.

CRITERIA FOR LIVING BREAKWATER SUITABILITY

Shoreline criteria describe the physical characteristics of the landscape and are one determinant of living breakwater suitability. Living Breakwaters are best established according to the following shoreline characteristics:

> Close proximity to shorelines in non-mooring zones.

> Living breakwaters are flexible in that they can be functional in a wide range of landward slope, underwater slopes, and erosion susceptibility.

> Living breakwaters can withstand moderate to high wave energy.

> Living breakwaters need to be located in the intertidal or subtidal zones.

In New England, the intertidal zone is subject to freezing air temperatures that may kill organisms living on breakwaters. Subtidal location protects organisms living on breakwaters from freezing temperatures.

In addition to shoreline criteria, additional environmental conditions affect the suitability of living breakwaters in the project area. The most relevant **environmental conditions** included:

> Water Quality

> Shellfish Beds

> 1% Storm Flood Zones

> Current Land Use

> Harbor Circulation

A Shoreline Criteria Model to Determine Living Breakwaters Suitability:

The shoreline criteria of the coast within the project area were measured and computed in GIS to identify sites that meet the physical requirements for living breakwaters.

The shoreline criteria measured included:

> Tidal Range

> Tidal Zone

> Fetch (Wave Energy)

> Bathymetry (Underwater Slope)

Areas that met all of these conditions were highlighted. Spaces within these areas overlapping with high boat activity channels and mooring areas were removed.

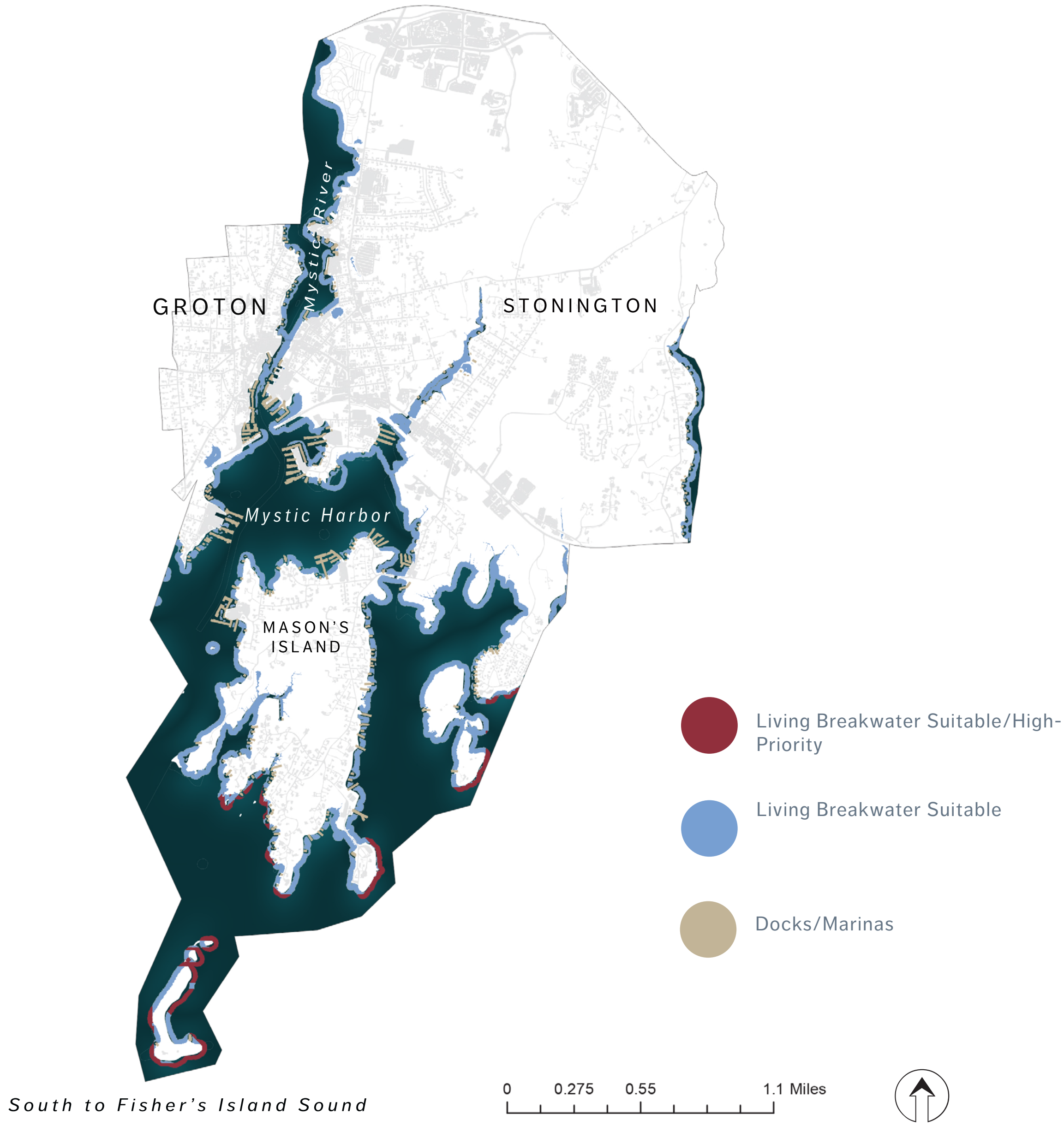
According to Mystic's 1995 Harbor Management Plan, a buffer around moored boats is essential to provide room for safe navigation. Moored boats are required to be located at least 150 feet from the shoreline in residential areas and 100 feet in commercial areas. Due to the absence of boats in this 100-foot nearshore area, living breakwaters are suitable as there is no direct conflict with moored boat activity. The boat-free zone (100-foot offshore area) was included as an area suitable for living breakwaters.

To maintain ease of boat navigability around piers and docks, a 50-foot exclusionary buffer was applied to account for incoming and outgoing traffic in mooring areas. A 50 foot buffer provides enough space for turn-around of boats; this area is excluded for consideration for living breakwaters due to conflict with boating patterns.

Results for the Project Area:

The outcome of the model was categorized as **suitable** and **suitable/high priority** for living breakwater placement. Both suitable and suitable/high priority categories meet the shoreline characteristics for living breakwaters, meaning that the sites possess a physical landscape well-suited to living breakwaters. The difference between the two categories is the level of exposure to the open ocean. Open ocean exposure indicates higher wave energy; shorelines that are protected by Mason's Island or lie within the Mystic Harbor experience lower wave energy. High wave energy translates to increased potential for erosion from daily tidal action and more destructive waves during storm events; these areas that experience high wave energy are deemed as high priority for living breakwater intervention.

LIVING BREAKWATERS
SHORELNE CRITERIA SUMMARY



Environmental conditions further informed research into the suitability of living breakwaters.

> Water Quality
> Shellfish Beds
> 1% Storm Intensity
> Current Land Use
> Harbor Circulation

High boat activity areas are potential areas for higher wave energy resulting in shoreline erosion. Water clarity and quality may be impaired by boat activity. Harbor circulation patterns indicate high traffic areas located within the narrow channel of the Mystic River and at its mouth, where living breakwaters would not be viable.

Flood zones for the 1% storm were mapped; areas within the Coastal V zone are the most vulnerable to storm surges. The most vulnerable areas were overlaid on the suitability map to determine high priority areas for implementing living breakwaters.

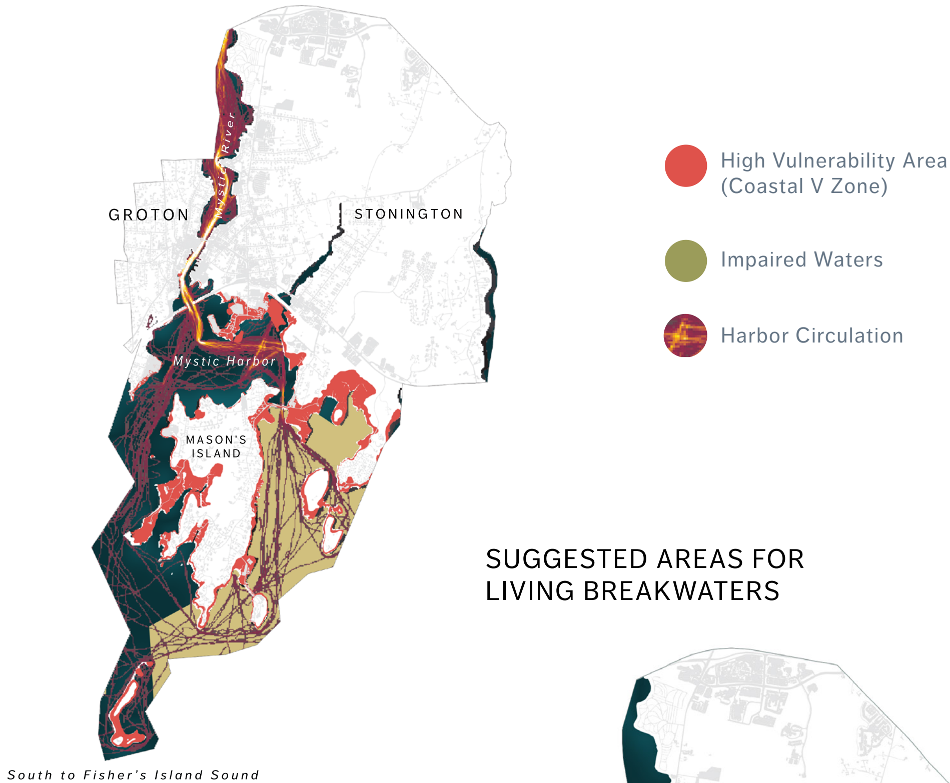
Analysis of existing shellfish beds, shellfishing jurisdictions, and impaired water zones were combined to understand how living breakwaters could affect current water quality and use. Living breakwaters may offer a co-benefit of filtering impaired waters, and living breakwaters that are dual-purpose (coastal resilience and filtration of impaired waters) could be a priority for the town to implement. Living breakwaters that are installed in existing shellfish beds could either augment or interrupt current shellfishing habits. Further site analysis will be necessary.

Results for the Project Area:

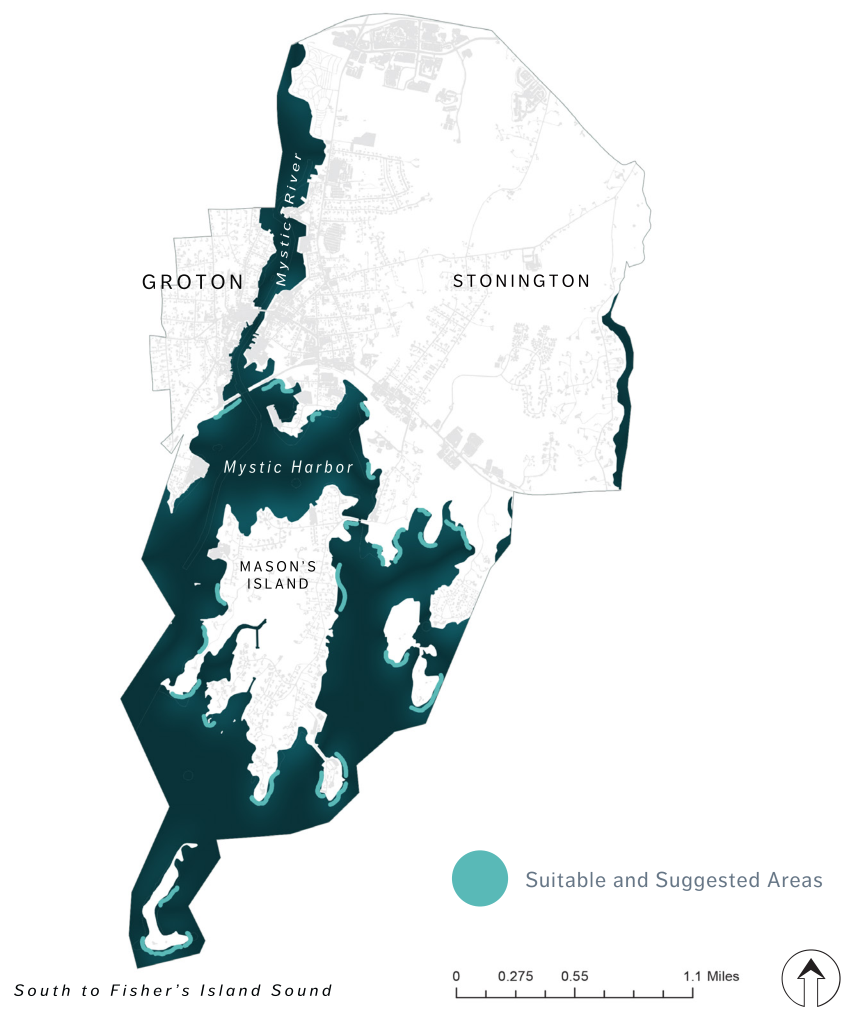
The analysis indicates areas where living breakwaters are most suitable and/or of high priority as well as areas where implementation should be avoided so as not to disrupt harbor circulation. The southern most tips of the land are highly susceptible to flooding and living breakwaters would provide the most protection in these areas.

Impaired waters to the east of Mason’s Island coincide with an area where both recreational and commercial shellfishing beds are located. This presents an opportunity for living breakwaters seeded with shellfish larvae to transform the degraded water into something clean and healthy for shellfish harvesting.

LIVING BREAKWATERS EXISTING CONDITIONS SUMMARY MAP



SUGGESTED AREAS FOR LIVING BREAKWATERS



Waterfront Residential

Non-Residential

Coastal Wetland Parks

Limitations and Future Considerations

Overview

Mystic is posed at an exciting moment to implement progressive coastal resilience strategies to provision for sea level rise and storm surge inundation and, by doing so, become a model for other coastal communities in the northeast.

The recommendations take a two-fold approach: living breakwater implementation and wetland connectivity as the foundation for coastal resilience. Community collaboration, which includes cooperation across sectors, is integral given the permeable boundaries of water. Sea level rise and storm surge inundation will effect land in Mystic regardless of parcel ownership and land use, therefore strategic, community-wide planning is necessary for the success of living breakwater implementation and wetland connectivity as coastal resilience interventions.

The recommendations are divided into four sections:

WATERFRONT RESIDENTIAL: Install living breakwaters and plant marsh vegetation for coastal resilience along private waterfront properties. This section outlines the methodology for site selection, the measurable gains of action, and strategies for funding, permitting, education, and financial incentives.

OPEN SPACE AND RECREATION: Anticipate and restore greater wetland connectivity throughout the village by creating space for the connection of existing tidal and freshwater wetlands.

NON-RESIDENTIAL: Integrate various scales of green infrastructure for coastal resilience on commercial, community, and non-profit parcels. Establish educational models of coastal resilience for other communities at key sites including the Mystic Seaport Museum and the YMCA at Williams Beach Park.

LIMITATIONS AND FUTURE CONSIDERATIONS: Plan for the future in light of unknowable dynamics of climate change. Outline extensive zoning amendments, smart growth, town pre-visioning. Reference case studies for managed migration and general evolution of coastal lifestyle.

Wetland Connectivity

DEFINITION

Wetland connectivity is a strategy for increasing coastal resilience by harnessing the ability of coastal wetlands to serve as protective buffers and valuable habitats. Increasing protection of these important ecosystems and the hydrological connections between them can help to maintain their ability to buffer areas from storm events and provide space for marsh advancement into these areas as sea levels rise.

As discussed in the wetlands analysis, the landscape of Mystic has a diversity of coastal tidal wetlands. These wetlands sequester carbon, provide wildlife habitat, and filter pollutants from water. Coastal wetlands offer coastal resilience by attenuating wave action and reducing the rate of shoreline erosion by capturing sediment.

THREATS TO WETLANDS

Conversion for development, land subsidence, sea level rise, and increasingly frequent hurricanes and storms are all threats to the health of wetlands. Patterns of historic wetland loss in Mystic reflect national trends from many centuries of settlement, but also represent a continuing issue of development today. According to a study on wetland loss in the US conducted by NOAA and the US Fish and Wildlife Service, “361,000 acres of coastal wetlands were lost in the eastern United States alone between 1998 and 2004” indicating that more direct action must be taken to reverse this trend (Stedman, 2008). While most of this recent loss has been attributed to development, there are additional issues related to land use change that contribute significantly to the problem. Large changes in land use can result in alterations to natural patterns of surficial hydro-geology that reduce sedimentation renewal rate within wetlands. This process of sediment moving over land, that would usually accumulate in wetlands and effectively maintain their elevation, are no longer in balance. The result is subsidence, when coastal wetlands are slowly sinking into the ocean and being loss (Stedman, 2008).

On top of subsidence, rising sea levels threaten tidal wetlands. Tidal wetlands occupy the area between low and high tide levels; as sea levels rise, the new high tide level can permanently submerge wetland plants. These plants are evolved to be intermittently inundated, not permanently submerged; submersion would result in habitat conversion or loss. Wetlands can maintain their elevation by accreting sediment. However, many studies have predicted that coastal wetland’s sediment accumulation will not be able to keep pace with rapidly rising ocean levels (Anisfeld, 2017). In some cases, dredged sand can be added to increase the elevation of wetlands in order to protect them from flooding by sea level rise, though such restoration projects are costly and may need to be repeated over time. Another option is protecting space to allow inland marsh migration. In response to this changing condition, a tidal wetland can migrate inland. However, dense existing development and pressure to continue building along the waterfront significantly constrain space for such advancement.

STRATEGY

The wetland connectivity strategy outlined promotes an action plan of protect and connect. *Protect* involves increasing wetland protections to mitigate the threat of development and preserve space for future marsh advancement patterns, and *connect* involves making wetland areas to allow these natural processes to take place.

Protect

CURRENT PROTECTIONS

Within Connecticut, wetland protection regulations are organized at the state and town levels. The state of Connecticut's Department of Energy and Environmental Protection has jurisdiction over tidal wetlands, however, municipal planning boards and conservation commissions are responsible for protection enforcement. Specifically, municipalities must ensure that land development and building projects do not degrade wetlands, preserve and protect existing tidal wetlands and, when and where possible, support the restoration of historic tidal wetlands (CT DEP).

Municipal protections take the form of wetland buffers established in zoning by-laws that are enforced by the local conservation commission. Currently Stonington's zoning regulations only require buffers for inland wetlands and establish no protections beyond the state jurisdiction line for tidal wetlands. This means that development is allowed right up to the wetland boundary, leaving no additional room for future marsh migration inland to compensate for sea level rise. Without the ability to advance forward it is quite possible that many existing tidal marsh areas will be lost to sea level rise, effectively reducing coastal protections in a time when climate change may also be precipitating more intense and frequent coastal storm surges.

The inland wetland buffer requirements in Stonington vary widely depending on zoning designation. There is great variance in buffer width between residential zoning areas, and no buffers regulated for any commercial or industrial districts (Stonington Zoning Regulations, 2018).

Varying Wetland Buffer Regulation By Zoning District

Zoning Category	Zoning Code	Zoning Description	Buffer	Conditions
Residential	GBR-130	Res., Greenbelt	100 ft	Non-Infringement Area
	RC-120	Res., Coastal		
	RR-80	Res., Rural	25-100 ft	Review by Commission
	RA-40	Res. Low Density		
	RM-20	Res. Moderate Density	50-100 ft	
	RM-15	Res. Moderate Density	25-100 ft	
	RH-10	Res. High Density		
	RA-20	Res. Single Family		
	RA-15	Res. Single Family		
Commercial	ALL	ALL	0 ft	No Buffers
Industrial	ALL	ALL	0 ft	No Buffers

Source: Stonington Zoning Regulations Manual

NEW MUNICIPAL WETLAND PROTECTIONS

Improved municipal wetland protections can ensure the preservation and continued health of existing tidal and inland wetlands. Increasing wetland buffers is a promising strategy for broadly reducing harmful impacts on wetlands and protecting space for future advancement patterns, without extensive land acquisition or major re-zoning. While the town cannot make large zoning changes in areas of existing development, increasing wetland buffers may offer a more achievable route to preserving existing marsh functioning and limiting new development near wetlands. Incentives may also be developed for existing non-conforming structures to comply to the new buffer regulations.

The town might explore establishing a consistent 100-foot buffer around all tidal and inland wetlands for all new development (residential, commercial, and industrial). The town might consider specifying in detail the actions/uses allowed within wetland buffers, using the CT DEP Tidal Wetland Buffers Guidance Document for supporting language (see Appendix I), this document bases its buffer recommendations on a strong body of scientific study on the ecological services provided by freshwater wetlands. As quoted in the document, The Scientific Basis for Protecting Riparian & Wetland Buffer Zones, a scientific review developed by REMA Ecological Services, indicates that ecological services provided by a 100-foot wetland buffer can include: 89% removal of sediment, 89.5% removal of nitrogen, and 82% removal of phosphorous (REMA Ecological Services). Additional studies have indicated that a 100-foot of tidal marsh can attenuate 95% of wave energy (Knutson, 1982) and recent 130-foot tidal marsh can offer 20% wave dissopation in high-energy storm conditions (Moller, 2014). The following guidelines for how to regulate wetland buffers has been adapted from the CT DEP Tidal Wetland Buffers Guidance Document:

HOW CAN MUNICIPALITIES IMPLEMENT TIDAL WETLANDS BUFFERS?

- Update zoning regulations to establish or increase protective buffers between development and all tidal and inland wetlands.
- Limit most activities and uses within vegetated buffers, with the exception of allowing access in relation to littoral rights or limited public recreational uses.
- Include specific standards for the removal of invasive species to maintain access, views, and ecological integrity of the buffer.
- Develop incentives for existing non-conforming development to relocate impervious surfaces outside of the buffer.

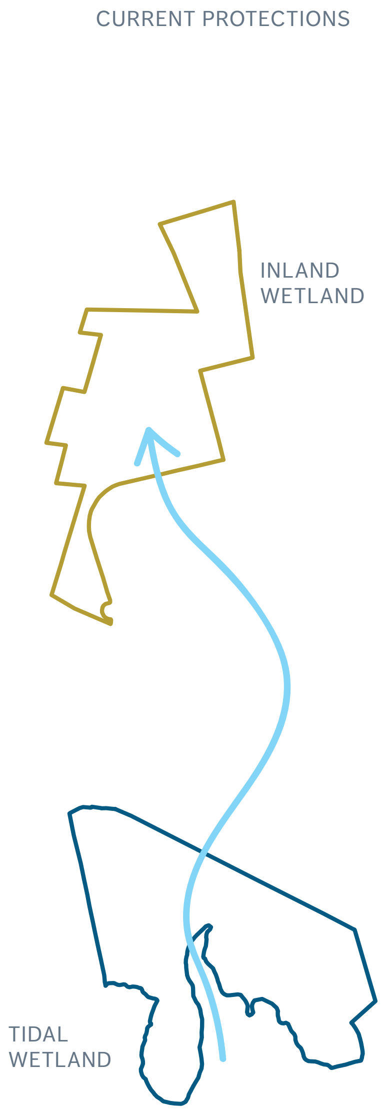
ALLOWED USES IN BUFFERS:

- Access in accordance with riparian or littoral rights in order to obtain access to a dock or boats.
- Managed recreational public access
- Planting and maintenance of native wetland plants
- Removal of invasive species including occasional mowing to maintain valued viewsheds.

RESTRICTED USES IN BUFFERS:

- New development including roads and other impervious surfaces
- The application of fertilizers, pesticides, or herbicides in order to protect the health of tidal wetland and adjoining inland ocean habitat

Connect



Wetland Connectivity also necessitates the reconnection of wetland areas in anticipation tidal wetland advancement inland to support the natural adaptive processes of these ecosystems and thereby ensure their continued protective functioning for coastal resilience.

Connectivity can have different meanings. Often wetland connectivity is discussed in terms of both structural connectivity, referring to the proximity of wetlands to one another and water's ability to flow between, and in terms of biological connectivity, which relates to the ability of plants and animals to move across the landscape in search of suitable habitats (Arthur Rylah Institute). In this project, wetland connectivity refers broadly to both structural and biological connectivity, focusing on maintaining or re-establishing hydrologic connections between wetlands that enable water to flow freely and habitats to adapt as sea levels rise.

This fluid movement is an essential component to the health and biodiversity of a given wetland, and also to the watershed as a whole. Waterways and especially wetlands have been fragmented or confined by patterns of development in highly developed areas such as Mystic Village.

Improving connectivity may require putting more land that is adjacent to wetlands into conservation and in some cases making infrastructural changes to remove impoundments to waterways and re-establish water flows. This is often done by daylighting streams or creating new culvert connections under roads or other infrastructure. Engineering analyses and plans must be developed to properly design the new or updated systems. When planning with climate change in mind, it is important to design these culverts to accommodate increased water flows by incorporating projected future ocean levels and precipitation events into calculations. Planning ahead can increase the lifetime of infrastructure, decrease future costs of repair, and increase coastal resilience by designing to withstand storms. Updating infrastructure to re-establish hydrological connections between wetland areas can allow these important coastal ecosystems to advance and adapt in response to changes in habitat conditions. By providing the pathway of adaptation, connectivity supports the continued health and utility of these wetland systems including their protective capacities to coastal communities.

MODELING WETLAND MIGRATION TO PRIORITIZE PROTECTION AND ACQUISITION

STATE OF MARYLAND

In response to the State of Maryland's Climate Action Plan (2008) call for the need to protect coastal natural resources in the face of the threat of future climate change, the state of Maryland developed a project to assess the impact of sea level rise on the current inventory of coastal wetlands. The Maryland Department of Natural Resources (DNR) in partnership with the Maryland Department of the Environment developed a computerized Blue Infrastructure Near-shore Assessment tool to inventory coastal habitats, critical natural resources, and land use along the state's coastal area. The project assessed the potential marsh migration patterns in response to sea level rise projections to identify future wetland areas. The model incorporated information on wetland size, location, regulatory buffers, and ecosystem connectivity to identify areas with the highest potential to provide protections and adaptations to coastal communities. The identified areas were then given a conservation score, created to assist local resource managers make better informed decisions and prioritize state funding to the most ecologically important projects. The results of the GIS-based model were also adapted into an online interactive tool, the Maryland Coastal Atlas as the Estuaries Wetland Change Tool that can be used by conservation professions, planners, and the public. (US Climate Resilience Toolkit).

Living Breakwaters

DEFINITION

Living breakwater implementation is a strategy to create a network of nearshore living breakwaters and offshore artificial reefs that can work together to reduce onshore wave impacts, improve the water quality in the harbor, enhance marine ecosystems, and support the local aquaculture industry.

Living breakwaters offer coastal resilience for exposed, high energy shorelines through the attenuation of wave action. As discussed in the summary analysis, there are a number of high vulnerability shoreline areas suitable for living breakwaters offshore of Mason's Island and within the Mystic Harbor. Living breakwater projects are proposed in the nearshore area to increase protections of these areas by breaking offshore waves before they reach shore, effectively decreasing the impact on the coastline and potential damage to waterfront properties.

Living breakwaters projects can be implemented as a layered approach, to add further protections to areas with marsh enhancement/creation projects and help marshes to adapt to rising sea levels. Living breakwaters can aid the success of tidal marshes by slowing wave action in the intertidal zone, allowing sediment to collect and gradually build up in elevation on the leeward side of the breakwater (Carey, 2019). As sediment collects and elevation rises, the intertidal zone can expand allowing tidal marsh to expand, increasing its size and buffering capacity behind the breakwater. Together, living breakwater implementation integrated with marsh-based interventions can offer a strong degree of protection with these dual components supporting each other over time.

Living breakwaters can provide the community with a number of additional benefits beyond coastal protections. Living breakwaters using shellfish can help to enhance local marine ecosystems by creating more nearshore habitat, which may offer opportunities for the local aquaculture industry to grow. The aquaculture industry in coastal Connecticut has recently seen a strong resurgence of smaller commercial operations and this trend can be seen locally with a number of commercial operations based in Fisher's Island Sound just south of Mason's Island and along the Mystic River.

A recent study released by UCONN shows the state's aquaculture industry having a significantly positive effect on local economies by providing both direct jobs on boats, and in aquaculture farms and processing facilities, as well as indirect jobs in sales, distribution, and the local restaurant industry (Turmelle, 2017). Recently, efforts have been made to strengthen both recreational and commercial shellfishing in Mystic. Stonington's Shellfishing Commission has transplanted oysters and clams into the recreational shellfishing area just east of Mason's Island for the past few years in an effort to re-establish a recreational harvest season (Wojtas, 2017). The Commission has also taken measures to facilitate its commercial permitting process to support what it sees to be an important cottage industry. Stonington's *Shellfish Management Plan* (2005) seeks to support the aquaculture industry, recognizing that the local shellfishing industry helps to diversify the economy and maintain the traditional working heritage of the area. The Plan views commercial harvesters as essential partners in the management of local shellfish populations and restoration efforts (Stonington Shellfish Management Plan, 2005).

It is hoped that living breakwaters can become a supportive feature of the local shellfishing economy by providing local jobs, increasing awareness around new green infrastructure techniques, and in doing so, forge new connections within towns between industry, conservation, and coastal resilience planning.

MANAGEMENT

There are a number of issues yet to be resolved relating to the implementation of such projects that must be acknowledged. As a relatively new concept, it is common that shellfish management plans, such as Stonington's, do not currently include policy geared towards the management and regulations of living shorelines. Policies need to be developed on how to manage the new habitats and mitigate any potential negative impacts, such as disease issues, on the commercial and natural shellfish populations (Carey, 2019).

Currently, the town and state of Connecticut does not have policy language for residential waterfront property owners managing and harvesting private oyster reefs. The practice known as "shellfish gardening" is currently not allowed at this time (DeRosia-Banick, 2019). However, the Bureau of Aquaculture does understand the growing interest in the use of oysters in living shorelines. Bureau officials have suggested that in areas with recreational harvest classification, conservation management plans could be developed by working with the local shellfish commission to protect and manage the shellfish community of the living shoreline, while allowing public harvesting (Carey, 2019).

Local aquaculture bureau officials have suggested that partnering with commercial shellfishermen may be a feasible solution. In such partnerships, a commercial operation could have the rights to harvest and sell the shellfish through a lease or a license from the town, in exchange for management of the structure (Carey, 2019). Engineers and resource managers familiar with marsh health also need to be included in the management of the tidal marsh on the leeward side to ensure proper drainage and mitigate potential stagnant water patterns that may negatively affect shellfish health.

STRATEGY

Designing breaks between the breakwaters, necessary to allow boat access, may help to alleviate this risk. Seeding artificial reefs may present a less complicated approach. Alternatively, artificial reefs, which are sited in deeper waters, may offer more accessibility for commercial operations. These reefs can be seeded with local mussels, offering opportunity to diversify the local shellfishing industry.

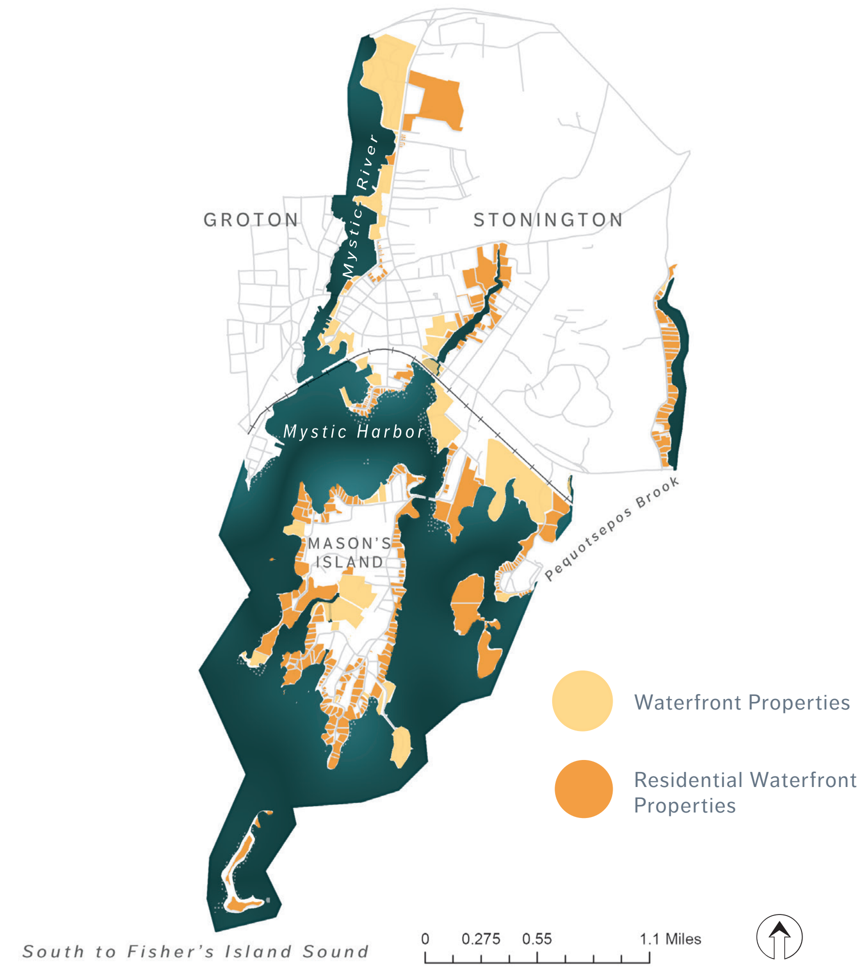
Living breakwater projects can help to improve local water quality, as discussed in the water quality analysis. With this in mind, living breakwater and artificial reefs could be designed with monitoring built into the project from inception. This may present an opportunity for further research and partnering with local universities to observe the effects of increased shellfish habitat on the harbor's water over time. Monitoring projects can help to measure the effectiveness of such interventions and provide management to assist the long-term success of these interventions.

Coastalresilience.org

ALABAMA COASTAL RESTORATION PROJECT
MOBILE BAY AND PORTERSVILLE BAY, ALABAMA

In 2009, The Nature Conservancy Alabama chapter received a $2.96 million grant through NOAA's American Recovery and Reinvestment Act to implement a large-scale living breakwater project along the coast of Mobile and Portersville Bays near Bayou La Batre. The project involved the creation of 54 miles of submerged living breakwaters, over 3 acres of oyster reefs, and over 30 acres of seagrass bed. In total the project protects over 10,000 miles of shoreline. The project sought to restore and protect coastal habitats by creating submerged oyster breakwater reefs that would also enhance the local marine habitat for fish and invertebrates. To achieve this project The Nature Conservancy worked with the Dauphin Island Sea Lab and the University of South Alabama for initial site analysis and design as well as continuing site monitoring post-construction (Coastal Alabama Restoration). One of the project's long-term goals was to boost the local fishing and shellfishing economies of the coastal communities damaged by hurricanes and extensive shoreline armoring resulting in habitat degradation. To this effort, TNC developed a workforce development program in partnership with local non-profits to provide work and training to unemployed people from the local seafood industry, teaching skills that would enable them to participate in future restoration projects within the Gulf of Mexico. TNC also partnered with the University of North Florida to develop a socio-economic analysis of the community surrounding the project site to determine how these types of coastal restoration and living shoreline projects might have lasting impacts on the economy and livelihood of coastal communities ("Coastal Alabama Restoration Fact Sheet).

Waterfront Residential



86% OF ALL WATERFRONT PROPERTIES ARE RESIDENTIAL

Living on or near water has historically been, and continues to be, desirable for many people, including the residents of Mystic. Of all waterfront properties in the project area 86% are residential.

While there are few residential properties along Mystic's waterfront, the shoreline of Mason's Island is almost entirely lined with residential properties and residences are concentrated within the Pequotsepos Brook inlet. Living in such close proximity to the sea comes with significant risk that will only increase as the years go by.

This section investigates how residential property owners, located along the shore, can better protect themselves and their homes in the face of climate change. There is an opportunity for these property owners to not only protect their own properties from storm damage, but also improve the town's resilience and protect its community assets by creating a living shoreline buffer.

Mason's Island

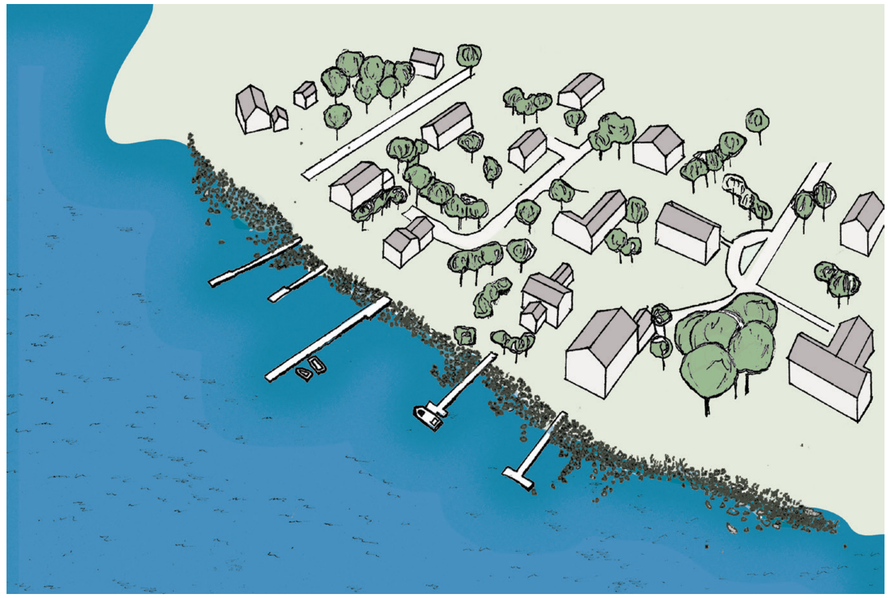
Mason's Island, referred by the Algonquin Native American tribe as Chippachaug, meaning a separated place, is situated at the mouth of the Mystic River. The island is Mystic's southernmost landmass within the Mystic Harbor and is the first line of defense against incoming wind and waves.

The marsh and living breakwaters suitability analyses (pages 83, 91) indicate the majority of all residential parcels along the shoreline of Mason's Island having the necessary site conditions for marsh establishment and living breakwaters. The following pages present concepts for a stretch of parcels along the Island's eastern shore. This area of focus was chosen because the residences are highly susceptible to flooding and sea level rise, away from boat congestion, and in an area where water quality is impaired, but levels of impairment are low enough for recreational shellfishing to still occur. Installing living breakwaters that employ bi-valves may help to improve the water quality.

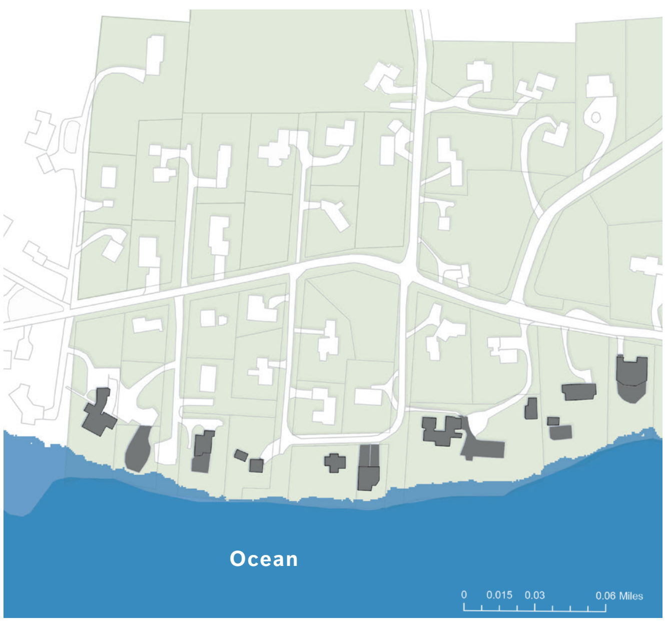
The following recommendations function as a template to be replicated in other waterfront residential properties along Mystic's shoreline and in other coastal communities, where applicable. This template is intended to inspire residential property owners to implement living shoreline strategies, and to help municipalities work with individual property owners to create a more resilient community. Further site analysis and storm surge modeling will be necessary before implementing these techniques.

EXISTING SHORELINE

The shoreline is a “rocky shore” consisting 75% or more of rocks with a thin strip of sparse vegetation. Replacing rocks with marsh vegetation can buffer residential waterfront properties from wave action.



SEA LEVEL RISE BY 2050



Sea Level Rise by 2050

By 2050, sea levels will rise approximately 20”. The encroaching sea level will create a distance as little as approximately 30 feet between some properties. Establishing living breakwaters will accumulate sediment for marsh to grow between the breakwaters and the shoreline as sea levels rise. Residents should also consider relocating their buildings as sea levels are expected to continually rise.

FEMA FLOOD ZONE

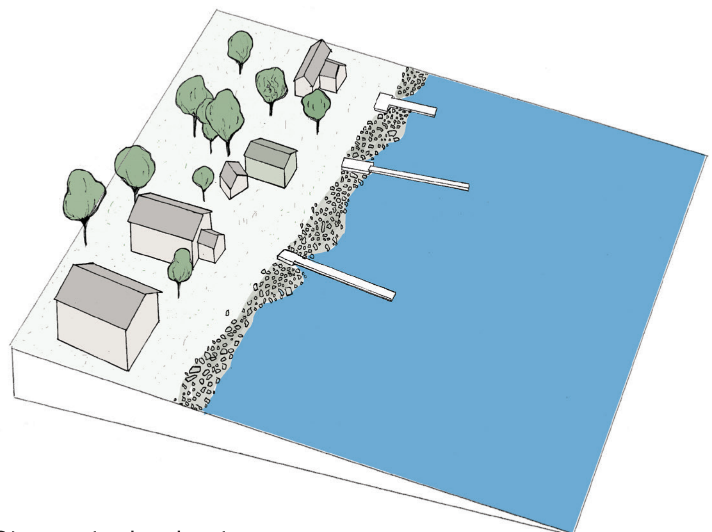
100-Year Floodplain   Flood Hazard Zone (FEMA VE-ZONE)

Currently the majority of waterfront properties are located within the 100-year storm floodplain and all waterfront properties are located within FEMA’s flood hazard zone. FEMA’s flood hazard zone is an area that is more vulnerable to the hazardous impacts of storm events than properties located further inland. Establishing living breakwaters offshore can help reduce the impact storm events have on the shoreline residences. Residents within the floodplain should consider elevating their buildings not just above base flood level (2 feet), but above the highest storm inundation level estimated for a 2050 100-year storm along the waterfront (6-10 feet) (FEMA 2050 100-year storm Data)

LIVING SHORELINE CONCEPTS FOR MASON'S ISLAND

It is recommended that waterfront residential property owners within the focus area soften their shoreline by replacing rip-rap with vegetation. Creating marsh habitat along the shoreline can buffer properties from wave action, and establishing living breakwaters further offshore can provide additional protection to the residential buildings and the marsh itself. If residential property owners intend to implement both living shoreline strategies, it is strongly suggested that the establishment of living breakwaters be the first course of action, followed by marsh creation, as the marsh is more likely to succeed in an environment with less wave intensity. Marsh species are able to adapt with the rising seas as they migrate upland as water levels encroach further inland. They also expand offshore as the accumulation of sediment provided by living breakwaters provides a growing medium for marsh species.

CURRENT SHORELINE:



Rip-rap is the dominant shoreline structure of residential properties along the eastern coast of Mason's Island.

WHAT IS RIP-RAP?

Rocks placed along shorelines or riverbanks to prevent erosion by stabilizing slopes; a common and conventional approach to help stabilize eroding shorelines.

WHAT'S WRONG WITH IT?

When water is deflected off riprap, wave energy increases, causing increased erosion to areas further downstream.

Riprap disrupts the natural functions of the riparian zone which typically consists of vegetation; these functions include pollution filtration, trapping and holding sediment, and providing wildlife habitat.

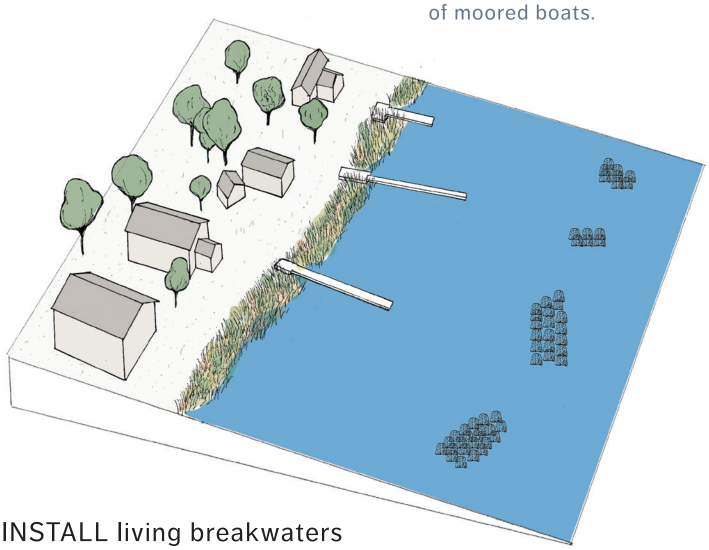
Uniform rip-rap shorelines lack the nooks and crannies that fish and other aquatic species require for shelter.

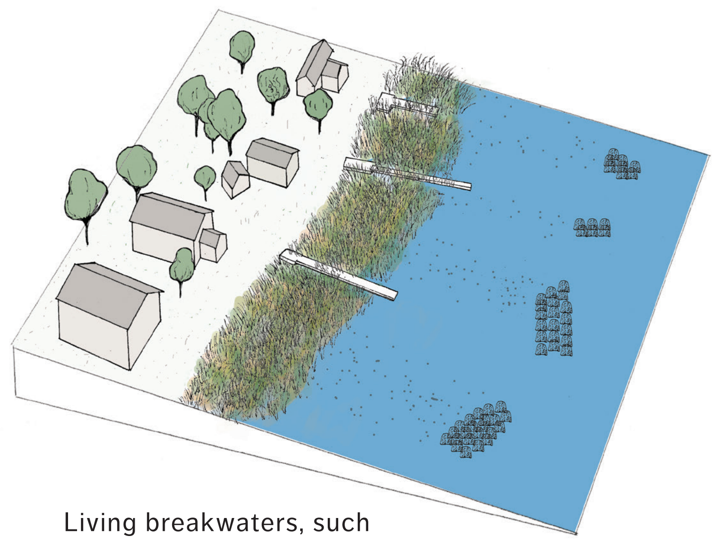
Rocks reflects direct sunlight into the water thereby increasing water temperatures.

WITHIN 10 YEARS:

IN 20 YEARS:

Breakwaters 100 feet from shore in an area free of moored boats.





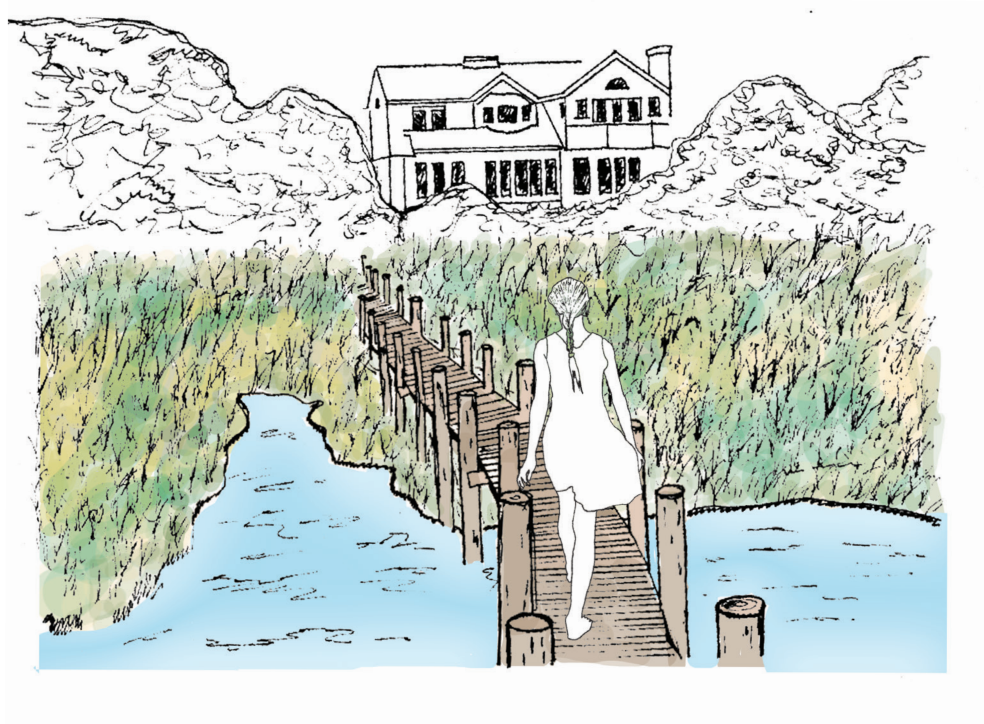
INSTALL living breakwaters between the subtidal and intertidal zone.

ESTABLISH marsh habitat within the intertidal zone, inland of living breakwaters.

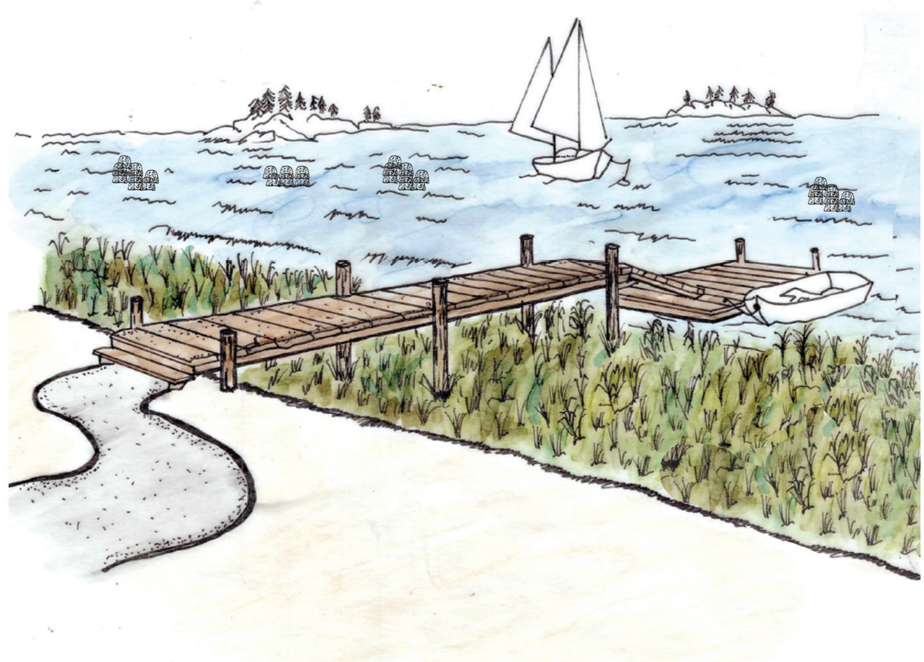
Living breakwaters, such as reef balls, encourage the accumulation of sediment behind the structures and within the expanding marsh habitat, which provides further medium into which marsh species can grow. This accumulation of sediment is extremely important to prevent marsh species from drowning due to sea level rise.

16 feet of marsh habitat reduces wave height by 50% (Subramanian et al, 2006).

Reef balls can attenuate 30% of wave energy (Mattei, 2017).



Residents living along the waterfront can transform their shoreline into a beautiful green space as a way of protecting their home. Waterfront property owners who invest in living shorelines reap the benefits of creating a protective buffer for their home, greening the shoreline and supporting wildlife.



Creating a living shoreline along a residential property does not have to disrupt the resident's interaction with their waterfront. Living breakwaters come in many different shapes and sizes, and can be arranged in a gap-like fashion to allow boats to navigate between them. While the property owner, after establishing a marsh, may not be able to walk directly into the water from shore, having a raised dock would allow them to access their boat or serve as a launching pad for marine activities like swimming or snorkeling.

CONSIDERATIONS	CHALLENGES	POTENTIAL SOLUTIONS
Implementing living shorelines within and across privately owned properties as a strategy to create a more resilient community is inherently challenging because municipalities cannot force individuals to integrate green infrastructure into their landscape; the resident has to take initiative. Additionally, if individual property owners decide to implement a living shoreline along their section of the coast, unless their property is of significant size, the living shoreline will not be as effective as it could be if an entire neighborhood implemented a living shoreline. The following table outlines potential obstacles when considering living shoreline implementation on a residential scale.	The shoreline traverses individual privately-owned parcels, but in order for marsh to be an effective buffer to wave energy it needs to be contiguous.	Create economic incentives for property owners to adopt coastal adaptation and resilience measures such as lowering the cost of flood insurance, providing tax credits/deductions, or commissioning a design for a stretch of shoreline in a waterfront residential neighborhood to build support.
	Individual property owners may possess different visions or aesthetic preferences, for their properties that don't align with living shorelines, which could result in patchiness or a fragmented living shoreline buffer.	Develop public education and outreach programs to inform residents of the ecological, economical, and protective benefits of living shorelines to encourage individual property owners to consider living shorelines for their properties. Building a living shoreline demonstration project on a residential property may increase interest amongst community members.
	Invasive species (*Phragmities*) might out compete high and low marsh species, and may impede the waterfront viewshed. Management of invasive species may be time intensive.	Provide free or low cost technical courses for residential property owners to learn how to install vegetative living shorelines and manage vegetation.
	Cost of implementation may discourage residents.	Provide accessible information regarding federal and local loan/grant opportunities.
	Lack of specialization/ knowledge amongst contractors may impede installation.	Provide specialized certification courses for contractors to obtain a living shoreline design specialization.

Steps to Incentivize

To help mobilize communities of private homeowners to begin the living shoreline implementation process, it is recommended that the town consider economic incentivization such as increasing the Town's participation in FEMA's Community Rating System for subsidized flood insurance rates.

Economic

FEMA's Community Rating System (CRS) is a program that recognizes and encourages community-wide floodplain management activities that exceed the minimum National Flood Insurance Plan (NFIP) standards. Communities are ranked according to their level of participation in mitigation projects and resilience planning, such as tightening building regulations and undertaking restoration projects. As a community engages in additional flood prevention or mitigation activities, residents become eligible for increased flood insurance policy premium discounts that can range from 5 to 45% off.

Currently, Stonington participates in the CRS, and is ranked as a class 8, which saves residents a combined total of $75,000/year. This discount rate could increase greatly with expanded participation in the system. Property owners in Mystic located in the Special Flood Hazard Zone, which includes most waterfront properties, only receive a 10% discount on flood insurance. This percentage could drastically increase if the town and residents were to implement climate adaptation and mitigation strategies, which includes but is not limited to, building living shorelines and adjusting building elevations.

STONINGTON'S CURRENT COMMUNITY RATING SYSTEM RANK

Rate Class	Discount for SFHA	Discount for non-SFHA	Credit Points Required
1	45%	10%	4,500+
2	40%	10%	4,000-4,499
3	35%	10%	3,500-3,999
4	30%	10%	3,000-3,499
5	25%	10%	2,500-2,999
6	20%	10%	2,000-2,499
7	15%	5%	1,500-1,999
8	10%	5%	1,000-1,499
9	5%	5%	500-999
10	0%	0	0-499

SPFH = Special Flood Hazard Area

Certification, Award, & Recognition Programs

Coastal communities like Mystic may consider developing a certification program that acknowledges and reinforces the environmental stewardship of landowners by providing public recognition, an award, or “green shoreline” certification. This not only provides well deserved positive feedback to the property owner, but may also encourage other property owners to get involved.

Towns could publicly recognize participating community members through newsletters, websites, or other media platforms.

This type of program seeks to normalize the practice of establishing a “green shoreline.” Creating an award/certification program that sets minimum requirements for landowners to achieve certifications may motivate and inspire landowners to get involved on a neighborhood-wide scale.

CASE STUDY

GREEN SHORES FOR HOMES certification program in WASHINGTON STATE is a voluntary, incentive-based program that motivates waterfront property owners to implement living shorelines by providing certifications. Similar to LEED programs, the more points a project achieves, the higher the “certification” awarded.

HOW IT WORKS:

Homeowners achieve “points” for each credit accomplished.

For example, residents who remove a bulkhead along 10-24% of the shoreline receive 2 points within the 1.3 “Remove groin or similar structures” credit.

Green Shores for Homes employs a neutral, approved third-party verifier to evaluate validity of awarded credits.

LEVELS of ACHIEVEMENT:

1. Chinook: 10-39 points

“Improvement/conservation of the natural features and processes of the shoreline.” (GSFH, 2015).

2. Orca: 40 points and above.

“Project exhibits exceptional design regarding improvement/conservation of the natural features of the shoreline.” (GSFH, 2015).

HOMEOWNER BENEFITS

- Instills a sense of pride for landowners who have spent time and money to create a living shoreline.
- Participation in the program provides financial benefits, technical assistance, reduced permit fees, tax incentives, and certification can be used as real estate marketing strategy.

Offer Education Programs

The success of residential living shorelines, specifically the health and effectiveness of marsh habitat, depends on residential property owners making change as a community by recognizing and valuing environmental shoreline stewardship. Informing landowners about natural alternatives to hard-engineered erosion-control shoreline structures and increasing landowners' awareness of the benefits, maintenance, science, and funding opportunities for living shorelines could generate community support.

Educational programs can take the form of public workshops for community members, planners, and professionals; outreach materials; weekly or monthly technical classes; an updated web page specific to Mystic; or living shoreline forums. Mystic could consider creating themed events like, "living shoreline awareness month."

The educators must possess technical experience or skills working in the field of constructing natural shorelines or be well-versed in the process of living shoreline implementation. Funds for such programs could be allocated from the local tax base or grants.

CASE STUDY

ADAPT CT : Climate Adaption Academy

The Center for Land Use Education & Research (CLEAR) & CT Sea Grant generated an online platform that provides information, tools, and resources for residents, municipalities, and businesses to learn about the effects of climate change and how to work towards adapting and mitigating it with natural infrastructure like living shorelines.

A workshop series is conducted every few months at various locations throughout the state of Connecticut. Three Living Shoreline Workshop series have been conducted in Groton and Waterford, CT, which brought in various professionals to cover topics including how living shorelines work, why they are important, and the permitting process associated with implementing living shorelines. Workshops also included a municipal/contractor panel discussion, analyzing case studies, hearing from design firms and reviewing their work with natural shoreline infrastructure, and a design charrette experience where community members engaged with experienced professionals to develop living shoreline designs at various locations.

The ADAPT CT website contains each presentation from the workshop series, updates on upcoming meetings, and additional online tools and information for landowners to learn from. See: https://climate.uconn.edu/

Mystic and other coastal communities could use this as a model for developing accessible resources for landowners or use this as a resource for developing workshop series or lectures.

Streamline Permit Process

Encourage individual residents to initiate living shoreline projects by creating a more inviting permit process. High Certificate of Permission (COP) fees and an extensive documentation process could deter individuals from pursuing living shoreline projects.

In the pre-application meeting, staff from the Land and Water Resource Division could review the purpose of the project and, if it meets criteria to be considered a living shoreline project with intentions to improve environmental conditions of the area and the intentions of the project do not consists of harmful environmental activities, such as dredging or filling, then the COP review process could be expedited. Voluntary living shoreline projects takes priority over erosion control structures like seawalls or bulkheads, and permit barriers could be reduced, such as a waived permit fee.

Consider creating a matrix of criteria to determine what defines a project as a “green” living shoreline project to be used in the pre-application meeting.

Consider how these projects will be monitored to ensure that construction and implementation maintains environmental integrity promised in pre-application meeting.

The Department of Environmental Protection Office of Long Island Sound Programs (OLISP) regulates shoreline use and development with the goal of minimizing adverse impacts upon coastal systems. The Coastal Management Protection Act (CMPA), created by the OLISP contains protective regulations for coastal resource areas by state jurisdiction and municipal jurisdictions. The CMPA regulates all activities conducted in tidal wetlands, and in tidal, coastal, or navigable waters under the Structures, Dredging and Fill Act and the Tidal Wetlands Act. PA 12-101 of the CMPA exempts living shoreline projects from the definition of shoreline flood and erosion control structures (hard-scaping) so living shoreline projects are not subject to additional municipal procedural requirements that apply to hard structures, like mandatory coastal site plan review and referral to DEEP. This aims to encourage waterfront property owners to prioritize living shoreline solutions over hard solutions. However, individual property owners looking to implement living shorelines along their waterfront still need to go through standard state and municipal permit procedures.

Residential property owners looking to implement living shoreline strategies will need to obtain a Request Certificate of Permission (COP) from CT's Department of Energy and Environmental Protection. In order to obtain a COP one must follow these steps:

> Consult with staff from CT's Land and Water Resource Division to explain intentions of living shoreline projects to determine the appropriate permit process.

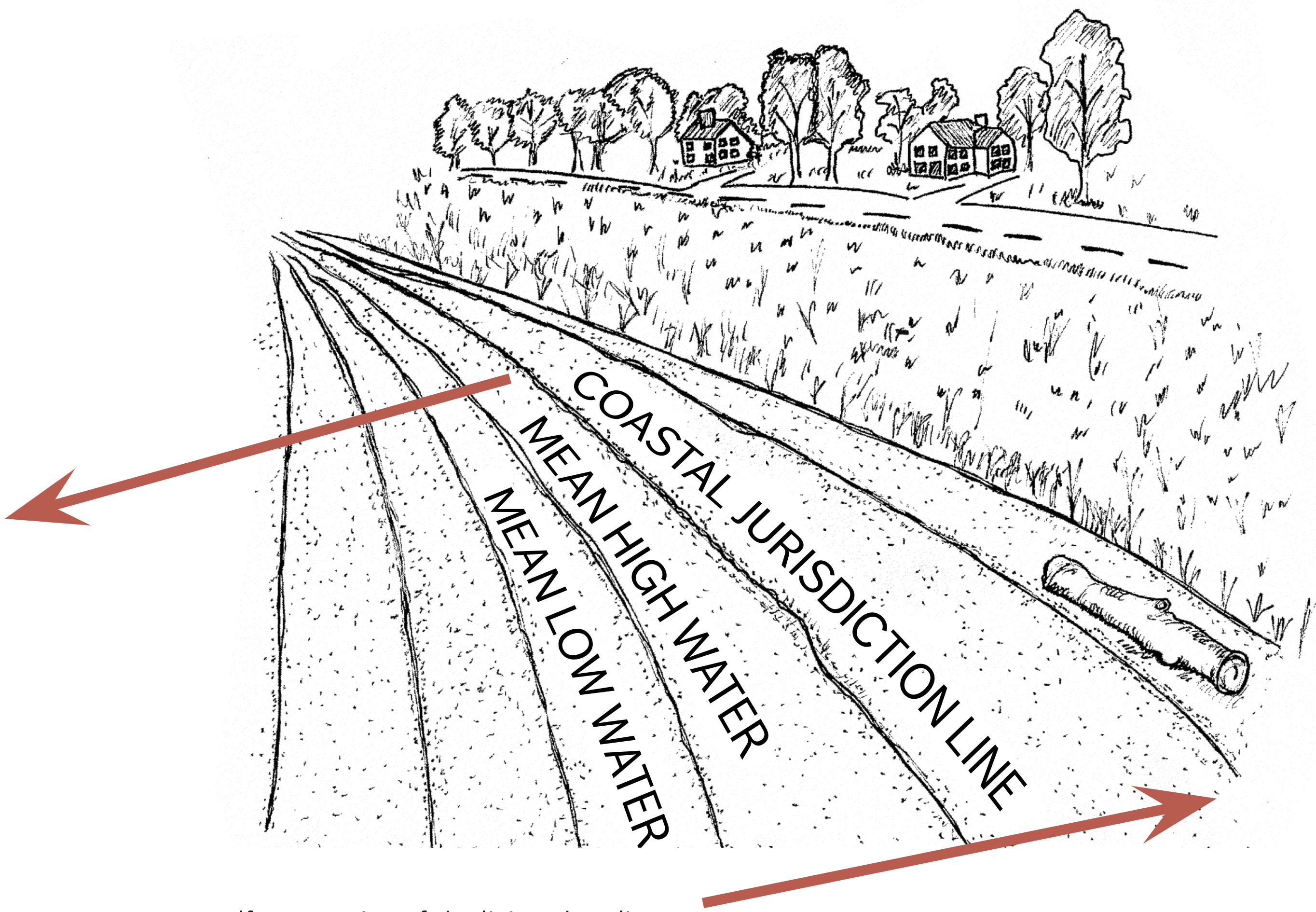
> A pre-application meeting is strongly recommended prior to the submittal of an application seeking authorization to work within tidal wetlands, or in tidal, coastal, or navigable waters of the state.

> The Department recommends individual residents consult with and/or hire a professional such as a land surveyor, engineer, or environmental/marine consultant familiar with the Department's permitting process who can assist in the preparation of an application and provide plans.

The Coastal Jurisdiction Line (CJL) in Mystic is 2.0' and CT's DEEP must be involved if the living shoreline strategy occurs water ward of the CJL.

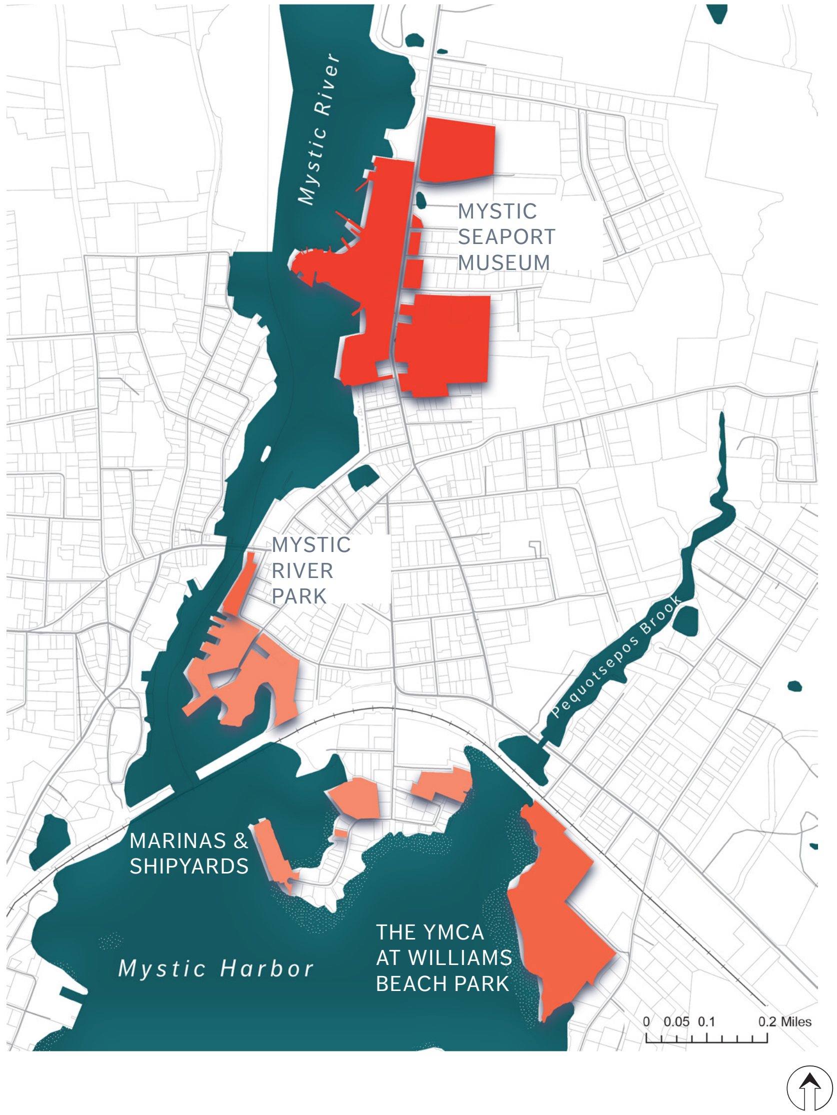
> Marsh enhancement/creation projects are located in the intertidal zone (below CJl) and are therefore under state jurisdiction

> Living breakwater installation occurs between the intertidal and subtidal region (below CJL) and is therefore under state jurisdiction



If any portion of the living shoreline strategy is conducted above the Mean High Water Line then individuals should notify their local Environmental Commissioner.

Non-Residential



Mystic Village has a highly developed coastline. The majority of properties in the village are residential, yet commercial, public, and non-profit properties occupy key parcels along the river and harbor frontage. These non-residential parcels are vital to the health of the community, specifically the community's recreational activities, like boating, and educational institutions.

Concepts for living shoreline interventions on commercial, public, and non-profit properties employ both living breakwaters and marshes to enhance coastal resilience.

These concepts take into consideration current land use and planned development in Mystic Village, while also proposing a more radical envisioning of future commercial zoning and tidal wetland protections.

Downtown Mystic

Finding space for coastal resilience interventions in the downtown area is a challenge because of the density of development, minimal available landward space, and the low elevation of the land.

There is little elevation change where land and water meet between downtown and the Mystic River. As such, vertical slopes, like revetments, are common along the Mystic River.

Pedestrian access to the river's edge is widely available throughout downtown Mystic; boardwalks and piers provide not only access to moored boats, but also a walking path for residents and tourists alike.

In terms of planning at the town level, initiatives to discourage development in tidal flood zones come to head with initiatives to continue economic development in a village-style.

HISTORY AT RISK

Mystic Village is unique as its downtown consists of two nationally registered historical areas—the Mystic River Historic District along the west side of the river and the Mystic Bridge Historic District along the east side of the river.

Within the historic districts, 351 historic buildings lie in the floodplain. The overall area is most covered by impervious surfaces. The combination of valuable historic buildings and impervious surfaces makes the area particularly susceptible to damage from inundation, as flood waters have no where to go.

RECOMMENDATIONS

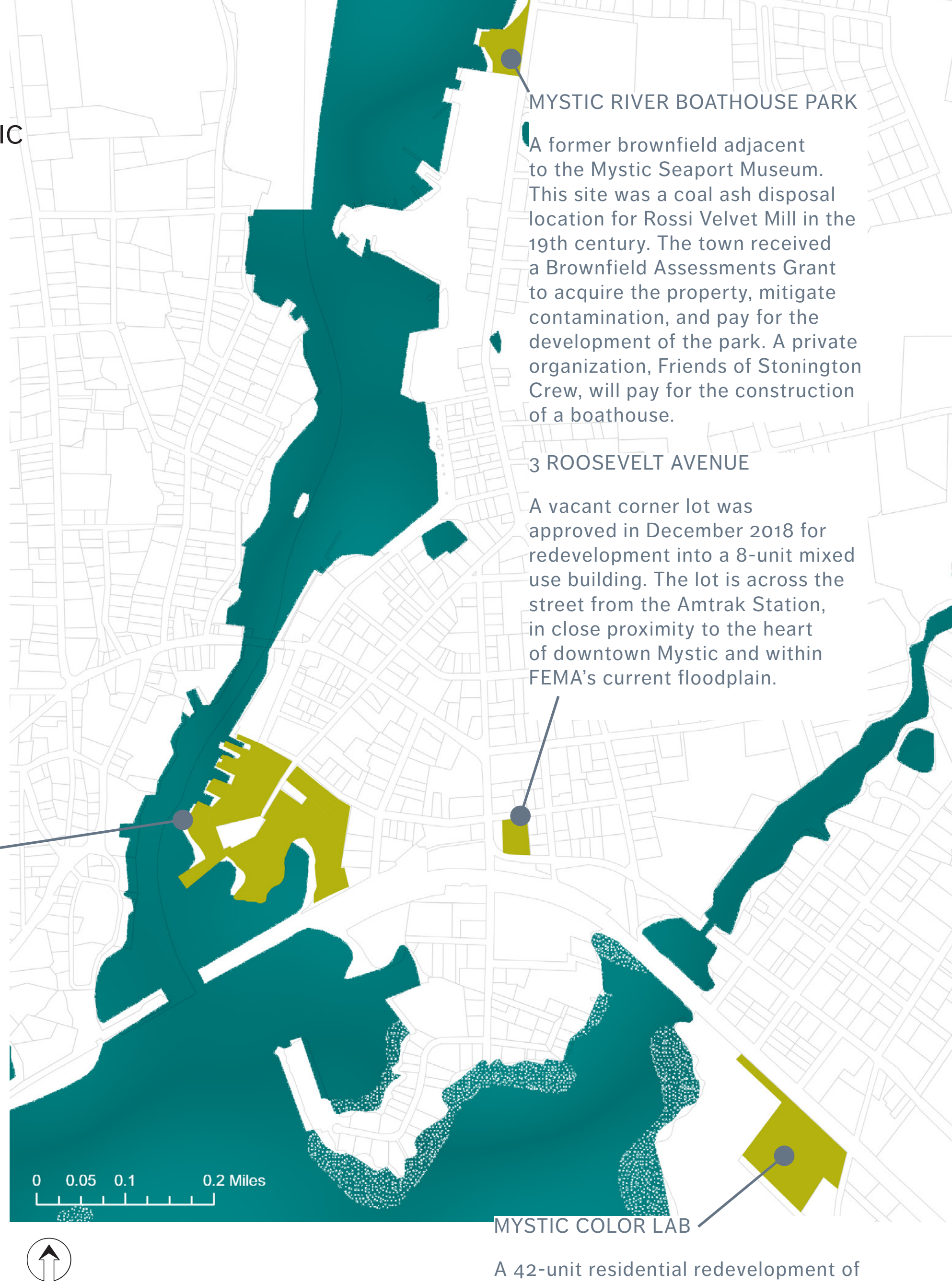
Resilience interventions for downtown Mystic will require a balance between the desire for development, the desire for coastal access, and the need to protect community assets. This report makes one recommendation for the downtown area—a re-envisioning of the Mystic River Park boardwalk—but the guiding design concept (diversity of edge conditions) is replicable throughout riverfront properties in Mystic.

CONSIDERATIONS: PLANNED DEVELOPMENT IN MYSTIC

Mystic Village is experiencing growth and development energy. In particular, young working professionals and families demonstrate increasing interest in property ownership and residence in Mystic. Real estate interest is reflected in the numerous development projects underway.

New construction in the coastal area has implications for the health of the shoreline and therefore the coastal resilience of the rest of the community.

The town of Stonington could balance the desire for new development and coastal resilience by revising the zoning and building requirements for new construction.



MYSTIC RIVER BOATHOUSE PARK

A former brownfield adjacent to the Mystic Seaport Museum. This site was a coal ash disposal location for Rossi Velvet Mill in the 19th century. The town received a Brownfield Assessments Grant to acquire the property, mitigate contamination, and pay for the development of the park. A private organization, Friends of Stonington Crew, will pay for the construction of a boathouse.

3 ROOSEVELT AVENUE

A vacant corner lot was approved in December 2018 for redevelopment into a 8-unit mixed use building. The lot is across the street from the Amtrak Station, in close proximity to the heart of downtown Mystic and within FEMA's current floodplain.

SEAPORT MARINE

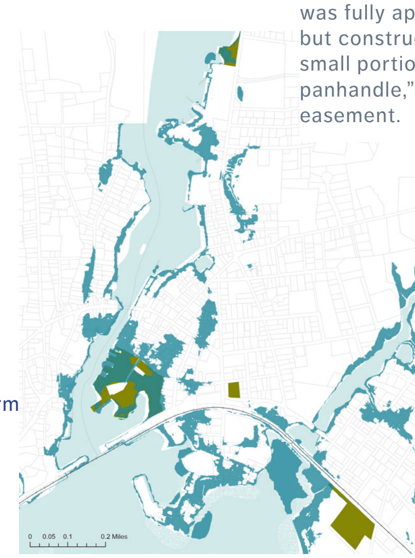
Seaport Marine is a series of parcels at the mouth of the Mystic River that totals 11.5 acres. The site is in the approval process for a complete overhaul. The historic shipyard and marina will be replaced with a hotel, public plaza, restaurant, apartment complex, townhouses, multi-family housing, marina, boardwalk, and kayak pavilion. The proposed development includes a steel bulkhead, dredge basin, and two 15-foot-wide living shorelines to account for sea level rise and storm surge inundation.

MYSTIC COLOR LAB

A 42-unit residential redevelopment of a former brownfield site; this project was fully approved by the town in 2017 but construction has not begun. One small portion of the property, "the panhandle," will be under conservation easement.

STORM SURGE INUNDATION

Storm surge models show that planned development in Mystic is within 2-10 feet of flooding from a 1% storm in 2050.



INTERTIDAL PROJECTIONS

The projected intertidal range, the area between high and low tide, in 2050 will reach the Seaport Marine Development and the Mystic River Boathouse Park.

REIMAGINING MYSTIC RIVER PARK

Mystic River Park, a 1.5-acre parcel, is at the heart of downtown Mystic. A broad swath of boardwalk forms the edge between water and land; it is level with the park green and offers little for shoreline resilience. In the summertime, visitors walk the boardwalk and sit on benches, visiting shops and enjoying the view of the river.

Mystic River Park is highly vulnerable to sea level rise. Sea level rise projections for 2050 indicate that Mystic River Park will overlap with the intertidal zone, the range between high and low tide levels. This projected coexistence with the intertidal zone indicates a high level of need for Mystic River Park to plan for increased daily flooding pressure.

Mystic River Park has a uniform edge, a boardwalk. A diversity of edge types is one approach to coastal resilience that integrates gray and green infrastructure. Just like an ecosystem, infrastructure resilience increases as the diversity increases.

The implementation of a diversity of edge conditions, using both gray and green forms, can serve as a model for other riverfront properties in the downtown Mystic area.

SITE DETAILS

Owner(s): Mystic Fire District

Area: 1.5 acre

Use(s): Park

APPROACH METHODOLOGY

Create Floodplain Terraces

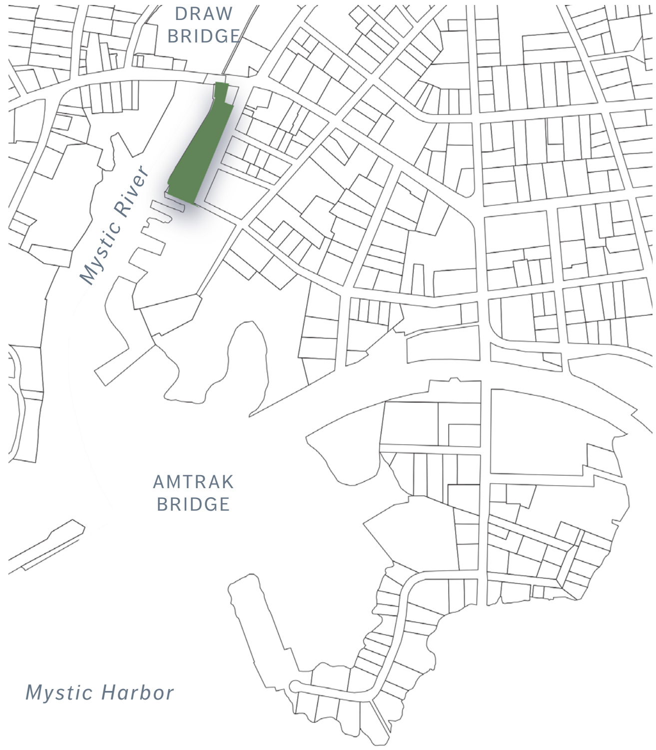
Soften Armored Structures

Diversify Edge Conditions

SPECIAL CONSIDERATIONS

Limited space

Historic character and aesthetics



REPLACE BOARDWALK

Tiered gabions offer a slight increase in elevation along the waters edge. The porosity of stones, held in form by wire mesh, and new plantings slow the incoming waves.

INTEGRATE VEGETATION

Water-loving plants occur in equal intervals along the gabion steppe and at the waters edge.

POST EDUCATIONAL SIGNAGE & CREATE NEW GATHERING AREA

Wooden planks create a new gathering area that is fun and safe for children to climb. Educational signage offers insight into the new design, the ecological value of the new vegetation, and coastal resilience for visitors. Educational signage may help with community buy-in.

WHY NOT LIVING BREAKWATERS AND MARSHES?

The two primary living shoreline intervention forms examined by this report, living breakwaters and marsh enhancement and creation, are not applicable to the current environmental conditions of Mystic River Park. The narrow width of the Mystic River and it's concentration of boating activity, coupled with the density of development on land means that there is not adequate space to implement these living shoreline interventions.

In a tight space, greening gray infrastructure and softening the overall armoring of the gray infrastructure can enhance resilience and offer benefits.

TIDE POOL GABIONS

Along developed coastlines, little space exists for landward interventions to account for sea level rise and storm surge inundation. In Mystic, this is particularly true as development comes up to the edge where land meets water.

Tide pool gabions along the Mystic River in downtown Mystic may, in some scenarios, offer an adaptive approach to coastal resilience.

Gabions are a conventional and affordable gray infrastructure technique to stabilize steep edges. Gabions consist of wire mesh boxes filled with stone; gabions often form stepped walls to create a gradual edge.

The use of grouped stone, rather than a flat material such as concrete, provides more surface texture that may potentially dissipate wave energy during strong water currents.

Tide pool gabions integrate elements of green infrastructure, creating spaces for vegetation and water pooling. Tide pool gabions might be a good fit for edges of downtown Mystic in place of a bulkhead.

Tide pool gabions can be incorporated with walkways to offer pedestrians access to the coastline and views of the water and exciting marsh plants. The vegetation selected for this area should range between low and high marsh species that can withstand a range of inundation.

Mystic Seaport Museum

The Mystic Seaport Museum (MSM) consists of a 19-acre campus along the Mystic River. With approximately 4,000 feet of river frontage, the MSM is a majority owner of river access in the village.

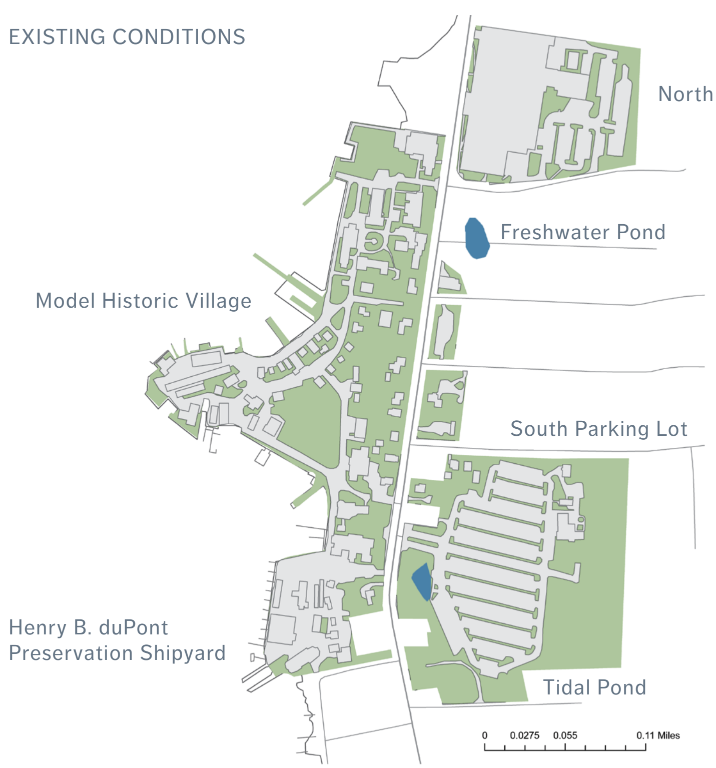
At the community meeting, attendees identified the MSM as a highly vulnerable area. Given its river frontage, the campus is at high risk for flooding both in the event of storm surge and more regular tidal pressure from sea level rise.

The MSM is a regional asset and a strong driver of tourism in the village. Some of its many historic resources include the Charles W. Morgan, the last wooden whaleship in the world dating from 1841, a model historic whaling village, and an extensive collection of maritime artifacts.

The Henry B. duPont Preservation Shipyard at the MSM is an active wooden shipbuilding facility employing historic methods. It's the workplace of 25 shipwrights as well as an educational asset for the public to observe the processes. The MSM is also a robust resource for college and graduate level research initiatives through Williams College and the Munson Institute.

In recognition of their assets and vulnerability, the MSM is in the process of resilience planning for the 2050 storm. The following concepts function as preliminary design suggestions. In the greater scheme of coastal resilience for Mystic, such interventions integrated have replicable elements for other area institutions, including the Mystic Art Museum, along the west side of the Mystic River.

EXISTING CONDITIONS



PROJECTED INUNDATION LEVELS
1% STORM IN 2050

1-5 feet

5-10 feet

10-15 feet

SITE DETAILS

Owner(s): Mystic Seaport Museum

Area: ~19 acres

Use(s): museum, research institution

APPROACH METHODOLOGY

Relocate Buildings

Create Marsh Park

Diversify Edge Conditions

SPECIAL CONSIDERATIONS

Account for limited space

Protect historic character and aesthetics

PLANNING FOR 2050

A map of inundation levels for the 1% storm in 2050 indicates severe flooding on the majority of the Museum's campus.

The area affected by flooding includes the historic village, the preservation shipyard, and administration buildings.

POTENTIAL STRATEGIES FOR 2050:

> Relocate model historic village. The village is located in an area of deep inundation and the cultural value at risk is high.

> Reduce south parking lot area to allow for the natural expansion of the existing tidal pond.

> Diversify shoreline edge conditions; integrate tide pool gabions with bulkheads.

> Replace central green with marsh park.

> Replace fixed piers with floating docks.

At the heart of the museum campus lies an open green space for visitors, including families and school groups, to picnic and play games throughout the year.

Currently, the green is surrounded by the museum's model historic village to the north and west. The south end of the green is directly exposed to the river.

The green lies at a low elevation, lower than the surrounding bulkhead that creates an edge between the campus and the river. As a result, regular flooding from the Mystic River already occurs during rain events and from tidal flows.

Given the low elevation, absence of buildings, and tendency to flood, the central green is a prime area for a marsh-based living shoreline intervention.

Sea level rise projection shows that by 2050, the central green will be mostly located within the intertidal zone. Based on this projection, the Mystic Seaport Museum could begin planting tidal marsh species and related upland species that are also salt tolerant.

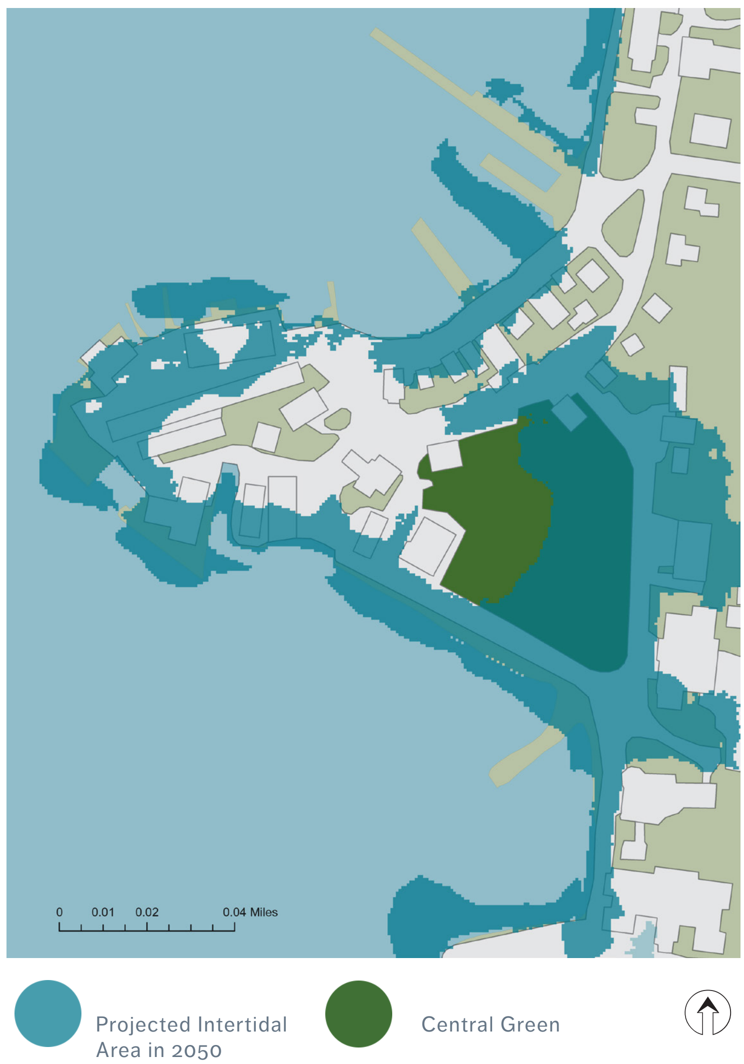
The new marsh-green is both a coastal resilience strategy and educational opportunity. By establishing a marsh, the Museum introduces a "sponge" to its campus. The sponge would serve as the first line of defense, absorbing incoming waters and lessening the impact of flooding further inland.

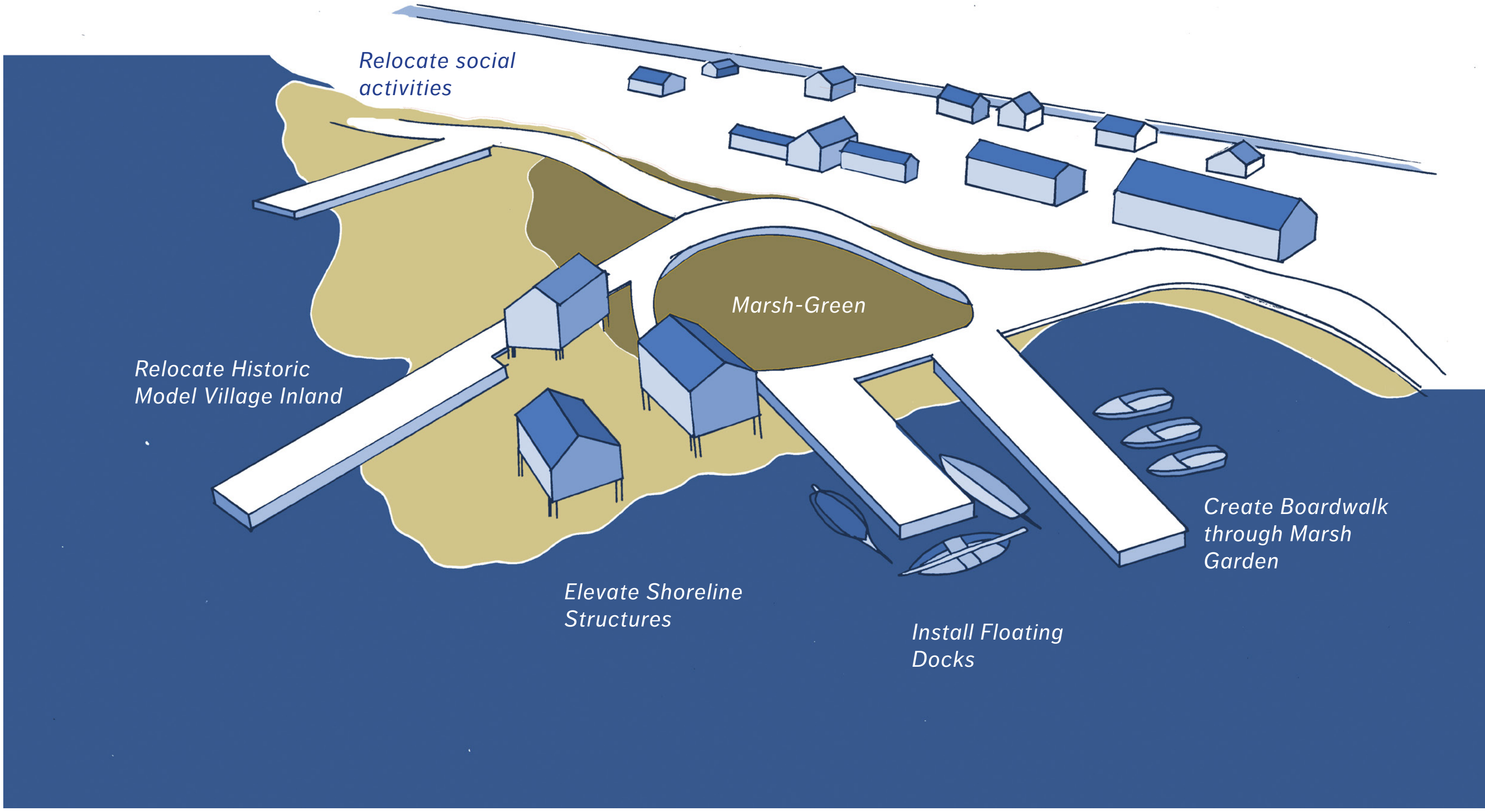
Marshes are critical natural habitats; educational programming on their ecological services, species varieties, and need for protection could be a regional asset in steps to protect wetland marshes on a larger scale.

Further research will be necessary to assess the health of the existing soil in the green and its drainage tendencies. It is likely that the space is heavily compacted from years of use and it is possible that sediment fill has been introduced over years of development in the area. Soil compaction and soil material type will have implications for the ability to establish marsh species. Soil augmentation, by fertilizing and aerating, may be a possible solution.

Steps to establishing a central marsh may include a site-scale engineering analysis to assess the feasibility of removing parts of the bulkhead. Removing the bulkhead would restore riverine connections and create a hydrological connection between the marsh park and Mystic River. The museum will also need to work with town and state authorities to determine the permitting process.

In the meantime, a transition away from lawn coverage and related landscaping practices, like mowing and fertilizing, will begin the conversion.





THE MARSH-GREEN

The central marsh would become an estuarine interidal habitat, hospitable to mixed herbaceous marsh species that are salt-intolerant.

The Mystic Seaport Museum can begin to consider how a new landscape, filled with native marsh species, could develop into a campus asset.

The marsh-green could include plant species like Swamp Rose, Sweet Flag, and Sea Lavender.

Sweet Flag

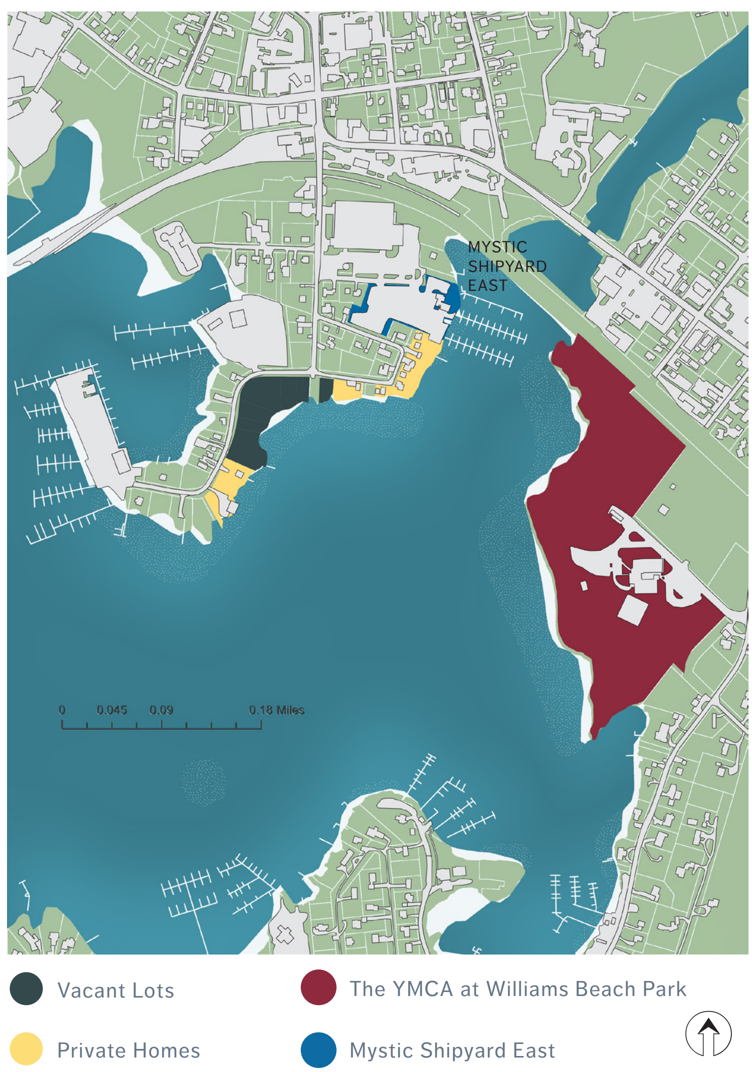
The YMCA at Williams Beach Park

The mouth of Pequotsepos Brook exemplifies coastal land use in Mystic. A historic and active shipyard and private residences share a small area with beach access, transportation infrastructure, and community recreational space.

Yet, recommendations for mixed-use and beloved coastal areas—like the YMCA at Williams Beach Park—are challenging to gain public buy-in. Coastal communities are hesitant to fundamentally change interaction with the coastline; proximity to the coast is often taken for granted.

The threat of sea level rise and storm surge inundation requires communities to seriously reconsider fundamental shifts. The area is vulnerable to sea level rise and storm surge due to its direct exposure to the Mystic Harbor and the Pequotsepos Brook.

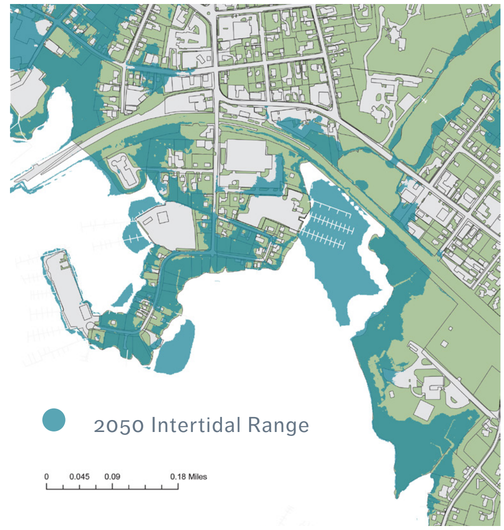
Intervention recommendations for the YMCA and the surrounding waters combine marsh enhancement and creation, expansion of tidal wetland buffers, shipyard and marina storm preparedness requirements, and living breakwater establishment.



NEW INTERTIDAL RANGE

Sea level rise projections for 2050 indicate that the intertidal zone, the range between high and low tides, will move inland. The vacant lots, private residences, and parts of YMCA are included within this new intertidal area.

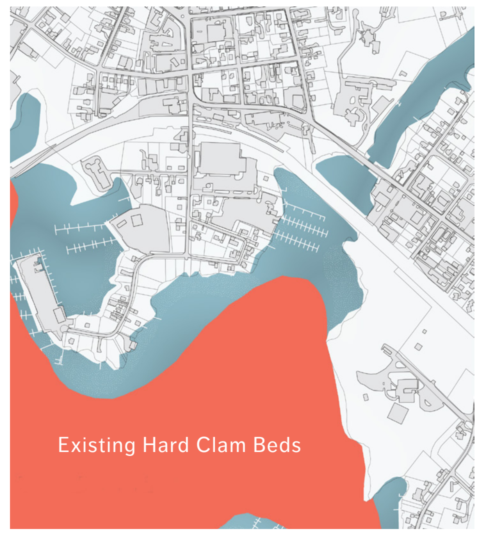
Coastal communities can choose to resist inland encroaching tidal range, or can choose to make land use changes to allow the water to move inland.



SHELLFISHING

Hard clam habitats are adjacent to the YMCA. The existence of hard clam habitats suggests that other bivalve species, such as oysters, are likely to live in the water here.

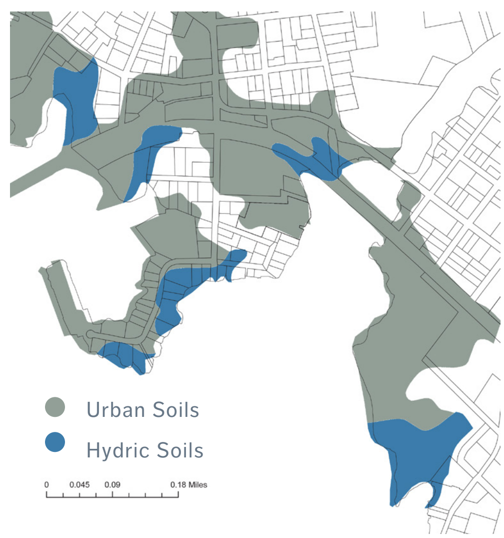
The presence of hard clam beds is not a disqualifier for living breakwaters. In fact, oysters, mussels, and scallops are all bivalves that create breakwater forms, meaning they attach to one another and create rigid structures. In contrast, hard clams do not build structures.



HYDRIC SOILS

Hydric soils form under conditions of saturation, flooding, or ponding for a long enough period to create anaerobic conditions in the soil (NRCS Soils).

The presence of hydric soils indicates the area is suitable for marsh vegetation or currently contains marsh vegetation.



URBAN-INFLUENCED SOILS

Urban-influenced soil classification reflects the term presence of development in the area; sediment fill was brought in to make the area buildable.

The presence of urban-influenced soils indicates that more study of the soil is necessary to assess its capacity to host marsh vegetation.

MOUTH OF THE PEQUOTSEPOS BROOK

The mouth of the Pequotsepos Brook is suitable for marsh enhancement, marsh creation, and living breakwater installation.

Marsh enhancement involves identification of vacant wetland areas, assessment of existing wetland health, and planting suitable marsh species.

Living breakwater installation requires collaboration across town and state jurisdictions, as well as collaboration with the Mystic Harbor Commission and local shellfishing enterprises.

The living breakwater location will overlap with existing hard clam beds. Living breakwater implementation may enhance the shallow water landscape for bivalve habitat and, by doing so, increase the population of hard clams in the area for recreational harvesting.

The greatest challenge to this recommendation is public buy-in. Overtime, private residences in the floodplain will be subject to higher insurance rates due to storm damage probability; therefore, stakeholders like home owners may be more inclined to sell land to the town and regional conservation groups.

The town of Stonington has the opportunity to strongly enforce buffer requirements around the intertidal zone, a highly vulnerable area.

SITE DETAILS

Owner(s): The YMCA

Mystic Shipyard East

Homeowners

Use(s): marina, public recreation, residential.

APPROACH METHODOLOGY

Connect Wetlands

Implement Breakwaters

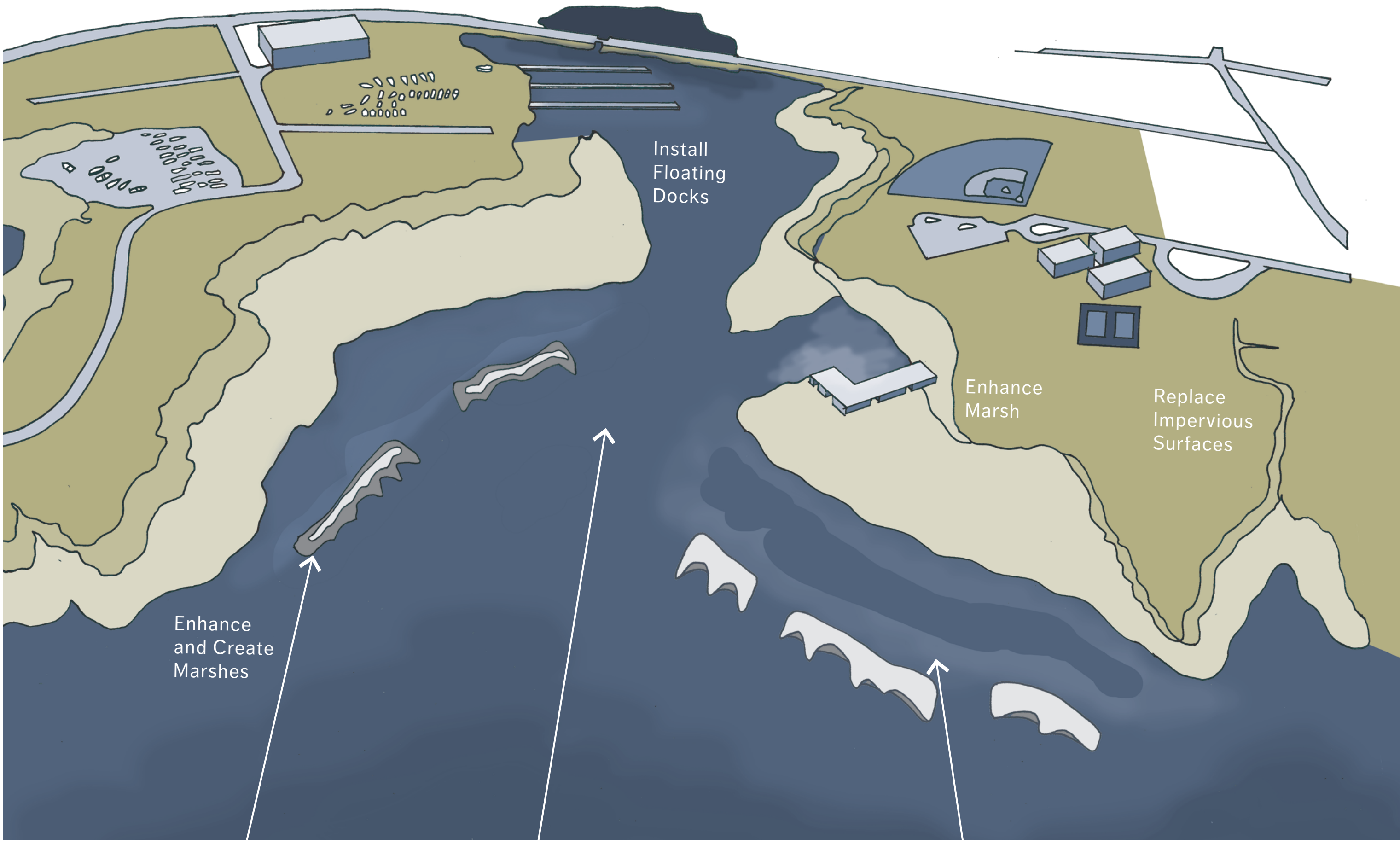
Re-Zone Floodplain and Acquire Flood-Prone Residences

Implement Storm Preparedness Requirements

SPECIAL CONSIDERATIONS

Public perception of land acquisition and rezoning.

Viability of breakwaters in high traffic zone.



SITE LIVING BREAKWATERS

The exact distance between living breakwaters and the shoreline varies depending on environmental conditions, specifically tidal range. Living breakwaters must be located within the subtidal, nearshore zone. The distance from shore ranges from 30-130 feet. Further site analysis will be necessary.

MAINTAIN BOAT AND KAYAK PATHS

Flags marking the living breakwater zones will help maintain ease of navigation in the area.

RESTORE SHALLOWS

Strategic location of living breakwater structures will help accrue sediment landward of the structures.

As sediment builds up, the shallow, muddy intertidal area will begin a process of restoration. Flora and fauna, like eelgrass and clams, thrive in the muddy, low water zone.

Coastal Wetland Parks

Within the project area 10% of parcels are undeveloped land. When faced with the question of how to integrate coastal intervention strategies into a densely developed shoreline, utilizing these undeveloped lands may represent a more readily available solution to finding space for change.

Re-imaging undeveloped land as coastal wetland parks using the strategy of wetland connectivity can create dynamic zones of coastal resilience and floodwater retention, while increasing community open space and public access to the waterfront. Redesigning large areas as floodable wetland parks recognizes the important protective capacities of existing coastal wetlands and protects them for their future utility as public assets. By incorporating wetland boardwalks and outdoor learning lab community spaces, wetland parks can provide new opportunities for recreation and education that can garner community buy-in and support pride of place.

Creating wetland parks by putting undeveloped land adjacent to existing wetlands and waterbodies into conservation and redesigning existing town open space to accommodate tidal and flood waters may increase coastal protections by expanding marsh areas and siting living breakwaters, while also increasing public recreational opportunities. Language in both *Stonington's Open Space Plan* (2007) and the *State of Connecticut's Coastal and Estuarine Land Conservation Program Plan* speak to the importance of both coastal resilience and recreational access to the coast in their guiding principles and conservation priorities. The community of Mystic has strongly expressed the desire for more recreational space (Stonington Open Space Plan, 2007).

Coastal wetland parks could address the lack of public recreational opportunities on the waterfront and coastal resilience in Mystic Village. Proposed wetland parks could be sponge-like with marsh species that absorb flooding and act as protective buffers between ocean storms and valuable coastal development, potentially diminishing the amount of flooding that reaches homes and businesses.

PROCESS

An overlay of the marsh suitability model, existing wetlands, areas subject to inundation, and land acquisition opportunities (in the form of existing open space and vacant lots) suggests locations for wetland parks. Areas subjected to highest inundation frequency indicate spaces most vulnerable to both current and future storm surges and sea level rise. These areas of lowest local elevation function as pathways where floodwaters move inland. Existing undeveloped parcels, including protected open space, unprotected green space, and vacant or unbuildable lots provide opportunities to connect existing wetlands with areas of projected marsh advancement thereby creating large areas of vegetative buffers.

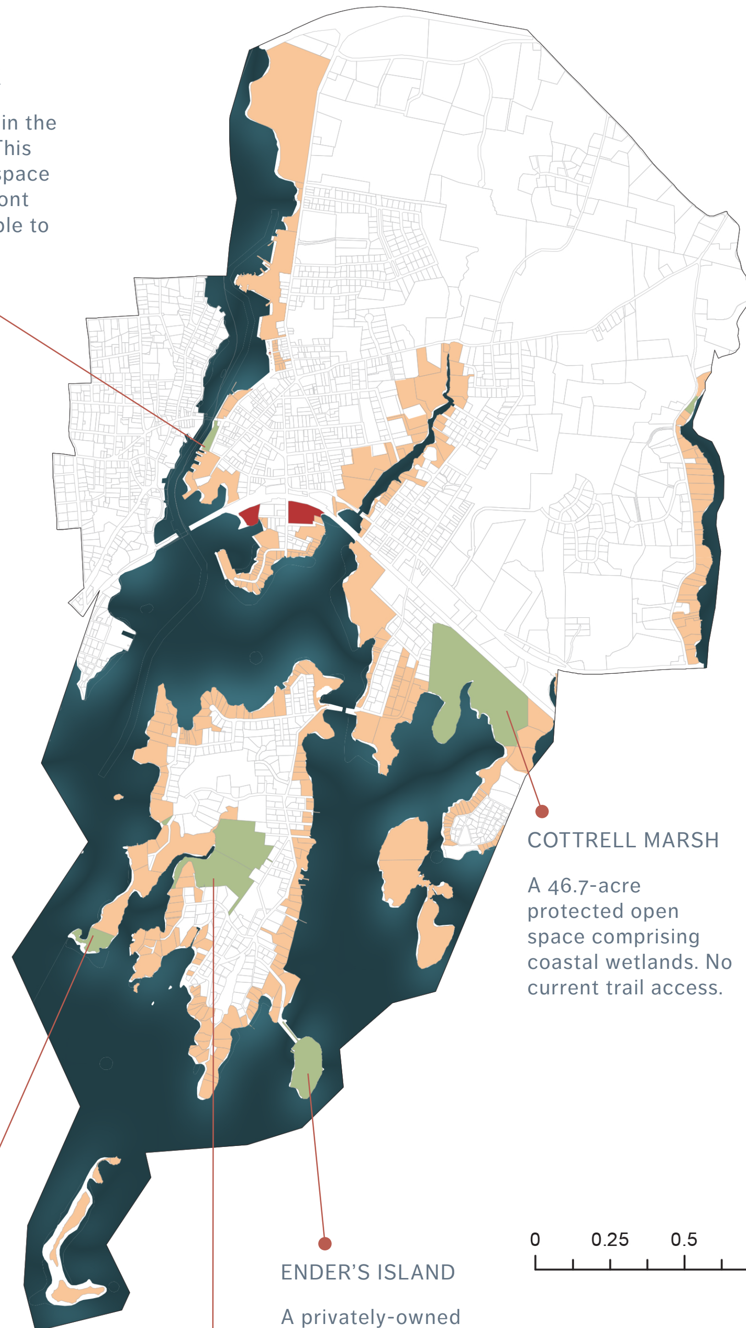
PUBLIC SHORELINE ACCESS

Currently, public access to the waterfront is limited in Mystic, as most of the waterfront is commercial or residential property.

A review of land ownership within Mystic shows this pattern clearly, with only a few parcels of public open space along the waterfront. Mystic River Park is one of these parcels, offering a highly valued community gathering space on the river boardwalk. While a number of large protected open spaces along the coastline have potential for public recreational access, few of these spaces currently contain trails.

However, these areas in some cases may be accessible by kayak or small boat. For the most part, large recreational space is confined to the water for boats and other water based sports, while access to the shore from the land is very limited.

Redesigning these open spaces as wetland parks could improve coastal resilience and expand public access to the water.



MYSTIC RIVER PARK

A small park located in the heart of downtown. This beloved community space is one of few waterfront green space accessible to the public.

COTTRELL MARSH

A 46.7-acre protected open space comprising coastal wetlands. No current trail access.

ENDER'S ISLAND

A privately-owned retreat is open daily to the public. Access may be limited during events.

GREAT MARSH PRESERVE

A 46.5-acre conservation easement managed by The Nature Conservancy.

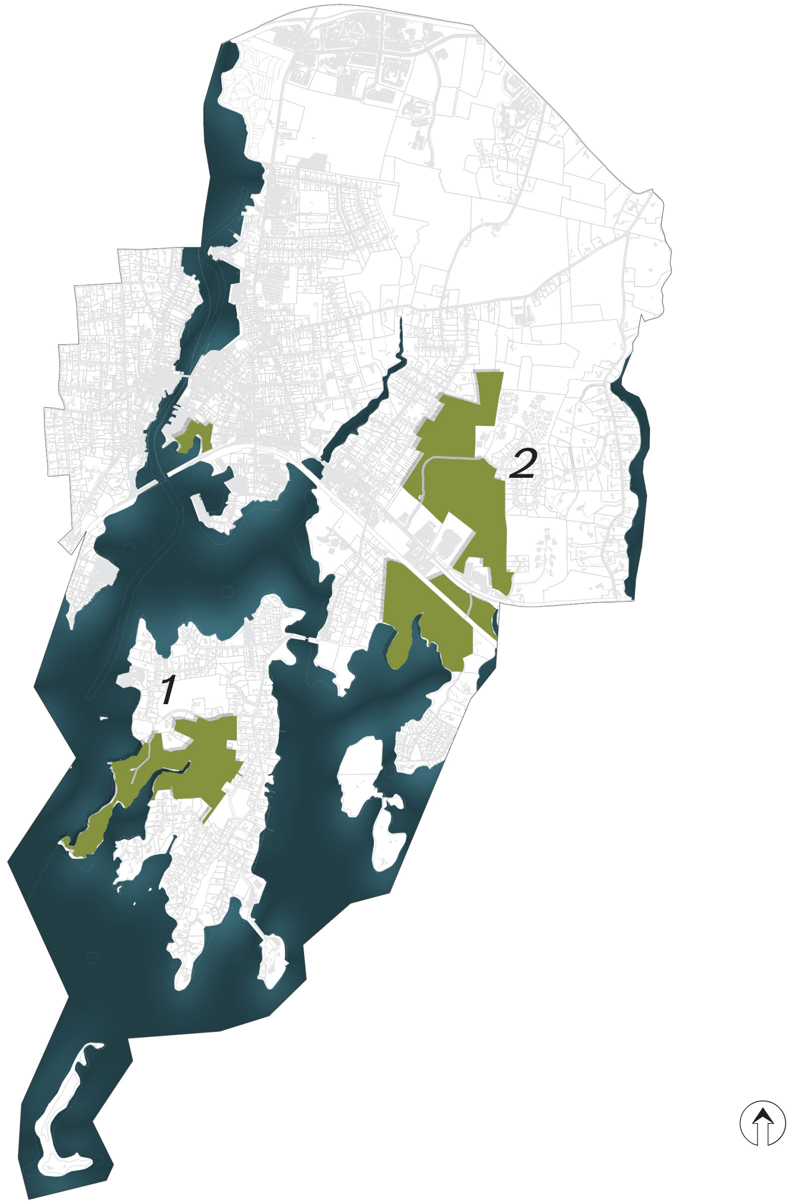
Contains trails available to Mason's Island residents and great potential for siting coastal resilience interventions and education components.

RAM'S POINT PRESERVE

A 4.6-acre protected open space containing both tidal wetland and higher elevation shrub habitat is only accessible by kayak.

POTENTIAL COASTAL WETLAND PARKS

Based on these design criteria, a number of potential sites for wetland parks were identified within the project area. These sites provide examples of how a wetland connectivity strategy can be used in Mystic to align coastal resilience with the town's open space and recreational goals. The following pages offer more detailed analyses of the proposed sites, walking through the identification process and including a discussion of the challenges specific to each location. These plans are preliminary designs with renderings meant to inspire a re-envisioning of these properties and communicate how changes could look in the future. While these specific sites are suggested for further study and acquisition, they can also be viewed as templates representing how undeveloped coastal land can be adapted for increased coastal resilience.



1 MASON'S ISLAND WETLAND COMPLEX

The southwestern point of Mason's Island encompassing Ram's Point has a high inundation probability from both future storm surges and sea level rise. Supporting the marsh expansion with added sediment, regrading, and protecting adjacent lands (currently privately owned) will increase the buffering capacity of these resource areas for the surrounding residential community.

2 SOUTHEAST MYSTIC WETLANDS PARK

Connecting the protected open spaces of Cottrell Marsh and Bishops Cove by protecting the wetlands in between and modifying existing infrastructure can allow for future tidal marsh advancement and increased protection of this residential side of the village.

Cottrell Marsh & Bishop's Cove

There is an opportunity to connect the existing protected tidal wetland complex of Cottrell Marsh with the inland brackish wetlands surrounding the open space in Bishop's Cove. This could be achieved by increasing wetland protections within the vacant lots that connect these two spaces and/or acquiring the privately owned parcels for conservation.

Acquiring connecting parcels between these two protected wetland areas could protect this space for the future inland migration of the coastal wetlands, thereby preserving this habitat as a protective buffer. Establishing a trail network of wetland boardwalks could serve the community by offering recreational access to a large currently inaccessible area. Outdoor learning space could be incorporated for schools and community groups to learn about the importance of coastal wetlands and observe the effects of sea level rise within their own community.

SITE DETAILS

Area: 108 combined acres

Owner(s):

- Avalonia Land Conservancy
- Bishop's Cove Condominium Association
- Adjacent Land Owners

Uses: Recreational

APPROACH METHODOLOGY

Connect Wetlands

Implement Breakwaters

Acquire Flood-Prone Vacant Lots

Create Conservation and Trail Easements

SPECIAL CONSIDERATIONS

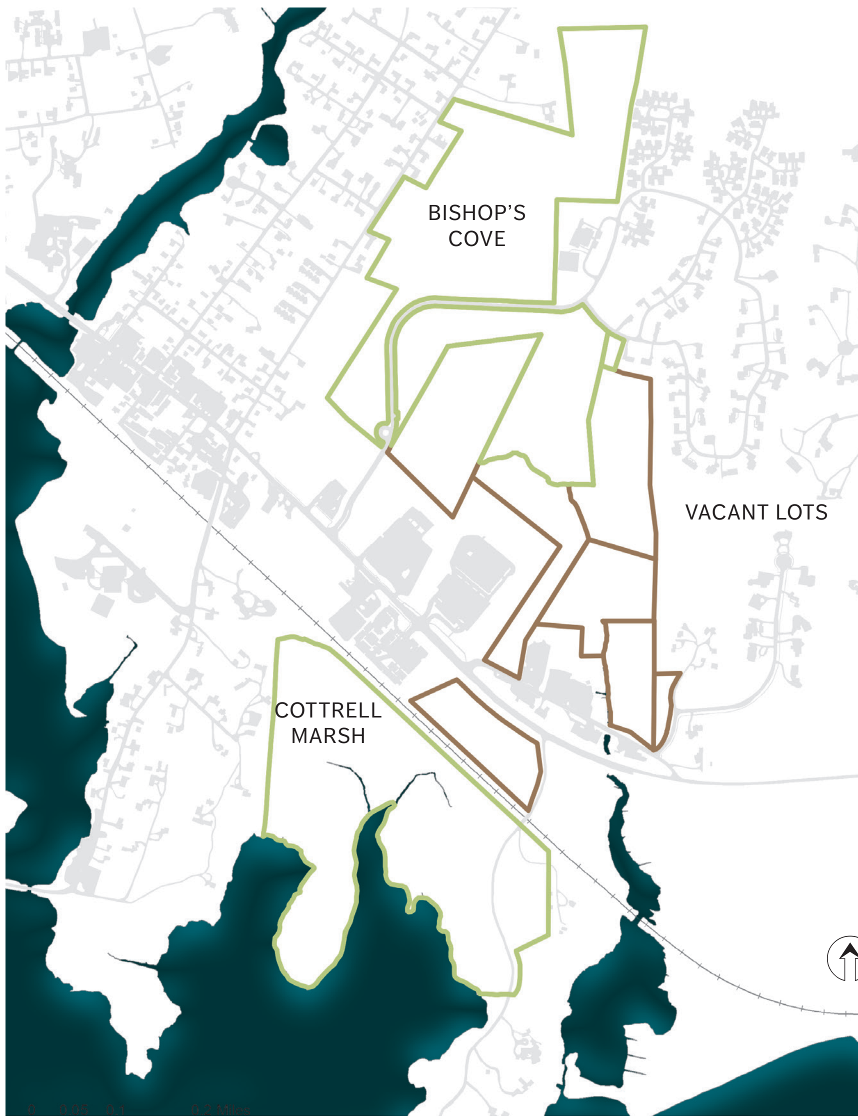
Land Ownership

Neighborhood Concerns

Increased Traffic

Parking Needs

Funding/Grants



COTTRELL MARSH is a healthy tidal wetland complex located east of downtown and south of the Amtrak railroad on Latimer Point in Mystic. The 46.7 acre property represents an intact coastal habitat of great diversity and importance to local shoreline and migrating birds, as well as acting as a shellfish and fish nursery. The CT DEEP Natural Diversity Database identifies 80% of the property as important natural communities hosting endangered and threatened species. Within this designated area CT DEEP has classified the intertidal marine estuary and coastal woodland as Critical Habitats.

The lower part of the property, dominated by tidal marsh, is cut with many tidal creeks that maintain natural tidal flows and drainage creating the conditions for a rich coastal habitat. The site hosts many native marsh grasses including Spartina species, Black Rush, Spikegrass, and Arrowgrass, as well as forbs such as Asters, Sea Lavender, Seaside Goldenrod, and Gerardia. This vegetation supports a healthy population of marsh invertebrates that in turn attracts feeding aquatic crabs and fish species, which provides food sources for a diversity of coastal birds. Bird species monitored on site include Osprey, Great Blue Herons, Great Egrets, Snowy Egrets, Glossy ibis, American bitterns, Yellow Crowned Nights Herons, Black Ducks, warblers, and Salt Sharp-Tailed Marsh Sparrows. Ribbed mussels are known to colonize the marsh's peat edges and the subtidal area between the marsh and Andrew's Island is known to be a popular recreational clamming spot. Upland areas of higher elevations near the edges of the property are filled with a mix of shrub habitat and wooded knolls dominated by native oaks with Tupelo, Sassafras, and blueberry in the understory.

The site was originally acquired in 1968 by The Nature Conservancy then transferred to the Avalonia Land Conservancy in 1992. While there are no trails through the wetland itself, the coastal area does provide passive recreational opportunities for kayakers and bird-watchers. The management plan for the property does allow recreational use and there remains an opportunity to expand public access if developed in a way that mitigates any potential adverse effects to the habitat. The location has been the site of many recent scientific studies and since 2015 has been used by the New England Wild Flower Society for collecting local ecotypes of native salt marsh seeds for restoration projects.

The future of Cottrell Marsh is uncertain given potential inundation from sea level rise. The management plan for the property developed in 2015 specifically states that the impoundment created by the Amtrak railroad tracks will prevent marsh migration. These tracks significantly inhibit natural patterns of sedimentation that would assist the marsh to adapt in elevation. The plan calls for the continued study of the site to monitor how the habitat responds to this impending threat.

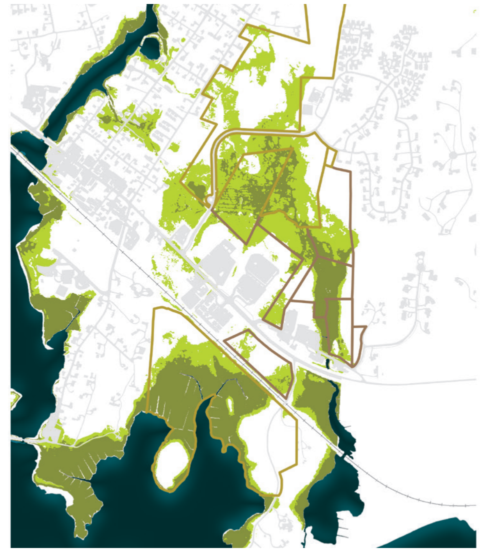
(Cottrell Marsh Property Management Plan, 2015)

SOUTHWEST MYSTIC WETLAND PARK
CONNECTING BISHOP'S COVE AND COTTRELL MARSH

Close up views of the marsh suitability model reveal this area to be a potential hot spot for marsh advancement. Storm surge probability patterns also indicate this area being a main flood pathway into the inland, correlating with the lower elevation of this area compared to the surround terrain. Accordingly, views of sea level rise and storm surge projections show substantial inundation putting the properties and road infrastructure in between these wetland areas in risk of frequent nuisance flooding.

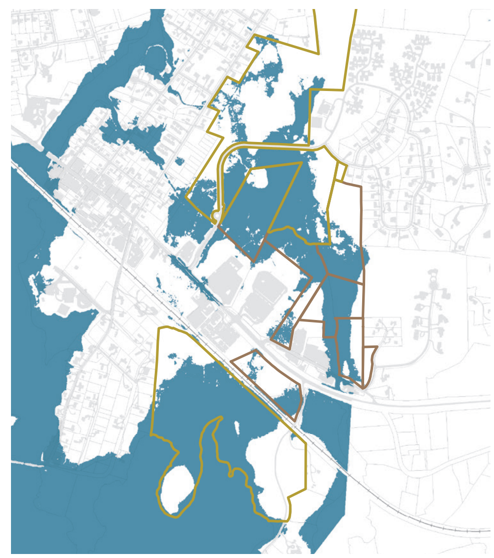
MARSH ADVANCEMENT

Results of the marsh suitability models indicate a large potential area of marsh advancement from the coastal area into the inland wetland



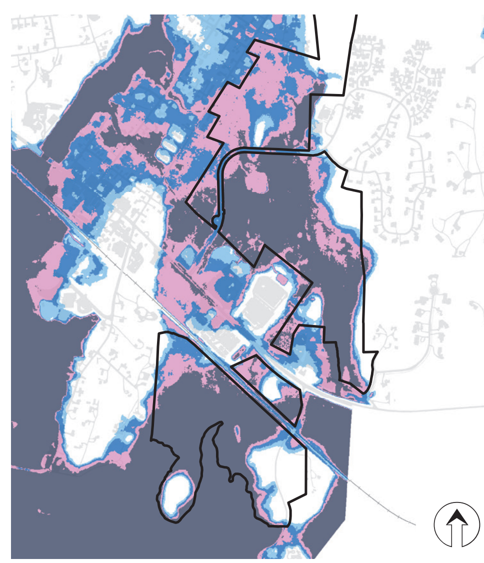
SEA LEVEL RISE IN 2050

Projected sea level rise will change the extent of the shoreline; the majority of these parcels will experience daily tidal flooding.



STORM SURGE PROJECTIONS CURRENT 1% STORM

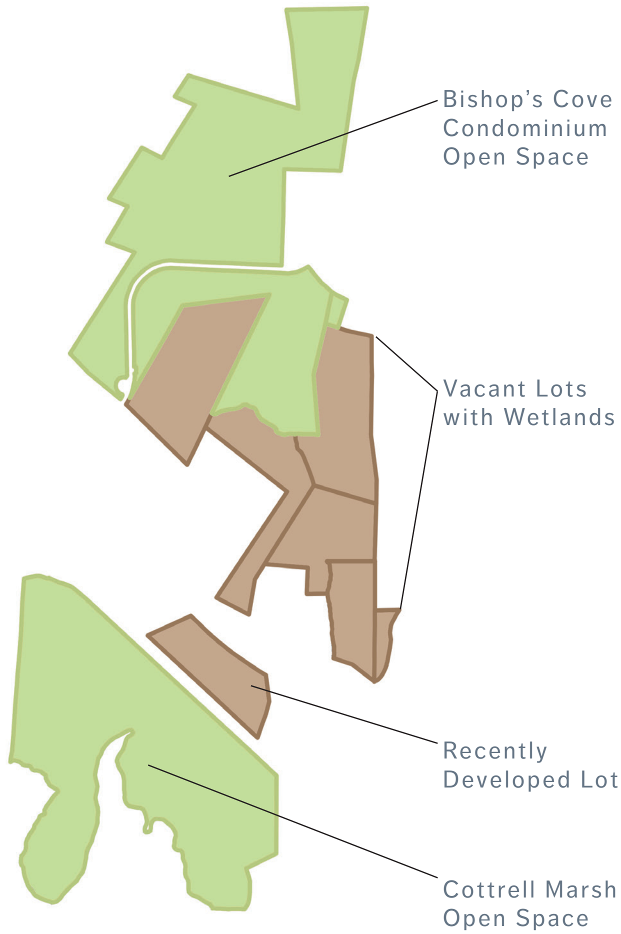
Storm surge probability maps show a inundation pattern suggesting that this area is a flood pathway

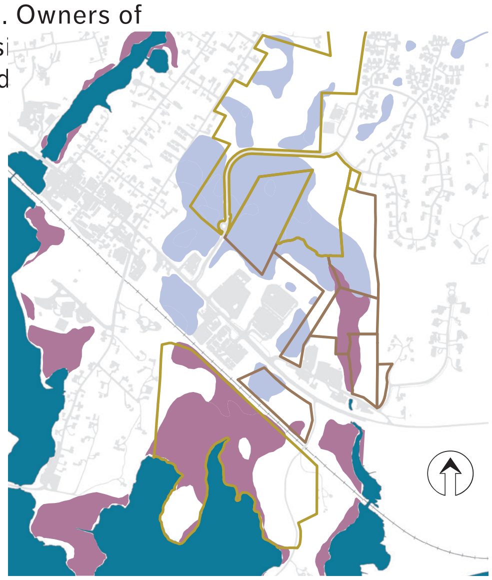


POTENTIAL CONNECTING PARCELS

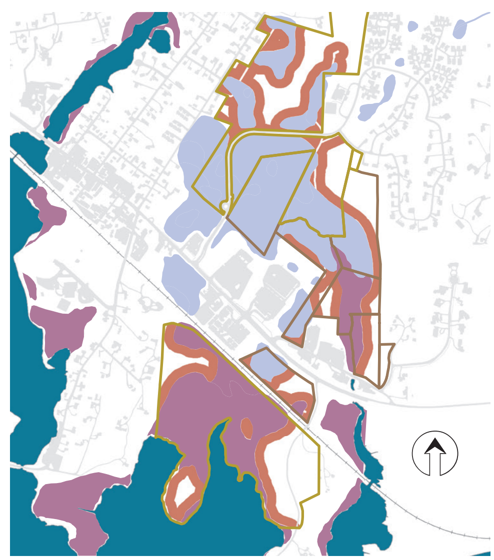
The vacant lots in this location are zoned Coastal Residential (RC-120), a zone that contains coastal areas including coves, estuaries, tidal marshes. This zone was established to protect these natural habitats and ensure flood protection (Zoning Regulations, 2018), and requires a 100-foot buffer extending from the delineated wetland boundary where no-development is allowed.

Due to the extent of existing wetlands, many of these lots have been designated as unbuildable. While development is unlikely in these areas, the pressure of residential development due to the high property value of coastal land may result in future building in seemingly confined locations. Due to this development pressure, increasing land protections through acquisition may be the best option for preventing more development in this high vulnerability area and protecting space around these wetlands to accommodate potential future marsh migration. Owners of vacant lots with extensi
may be more interested





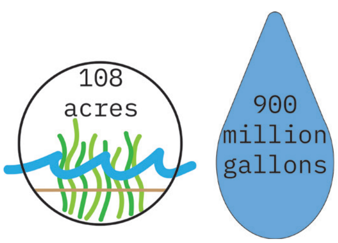
Parcels that comprise the proposed park space consist of protected open space (green) and vacant lots (brown).



Wetland protection buffer requirements differ depending on a parcel's zoning. Mapping this buffer (in orange) helps identify what ares of wetland lack current protections and thereby prioritize parcels for acquisition.

ADAPTATION + MITIGATION

Creating wetland parks is both an adaptive and mitigative strategy in response to climate change. If the area of the southwest wetland park were supported to convert into tidal marsh by protecting land for future migration and restoration projects, the resulting tidal wetland complex could offer a significant capacity to hold floodwaters and store carbon. The combined area of 108 acres, if converted to marsh, could hold over 900 million gallons of water. The space could also help to drain and clean upland stormwater during heavy precipitation events.

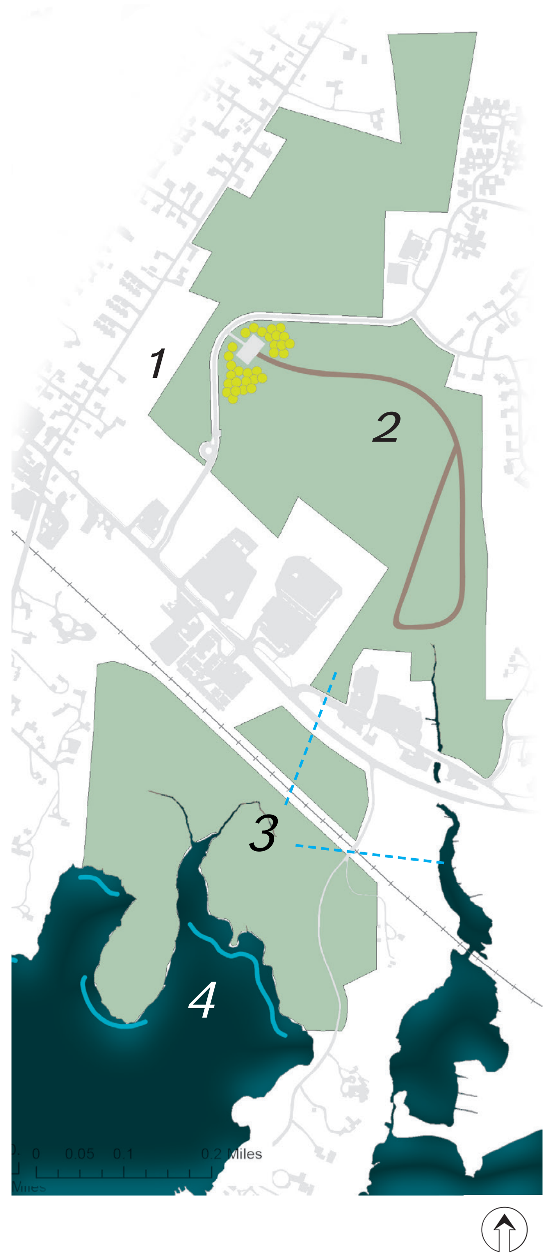


1 PARK ENTRANCE

An existing road with roundabout could be redesigned into a small parking lot with bike parking to encourage alternative transportation and limit an increase in traffic to the neighborhood.

2 TRAIL NETWORK WITH WETLAND BOARDWALK

A walking trail connecting higher elevation areas along the edges of the park could take the form of a loop trail offering recreational opportunities for local residents and visitors. Incorporating boardwalk sections could bring people into closer interaction with the marsh. These spaces could serve as outdoor learning labs to be used by local school groups and allow visitors to observe their local environment.



3 MODIFY INFRASTRUCTURE

Connecting these wetland areas would necessitate making modifications to existing infrastructure that currently has fragmented these spaces, preventing water movement between Cottrell Marsh and the inland wetland.

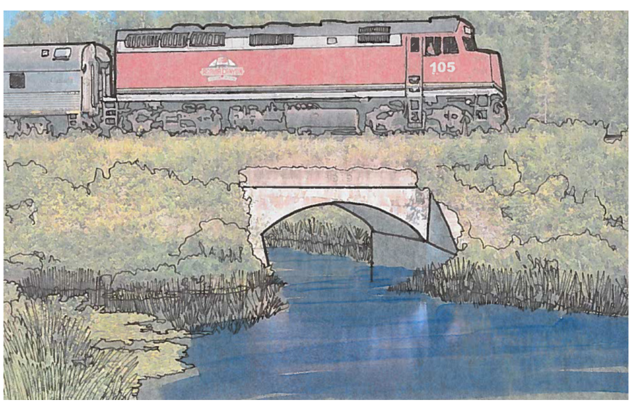
4 IMPLEMENT BREAKWATERS

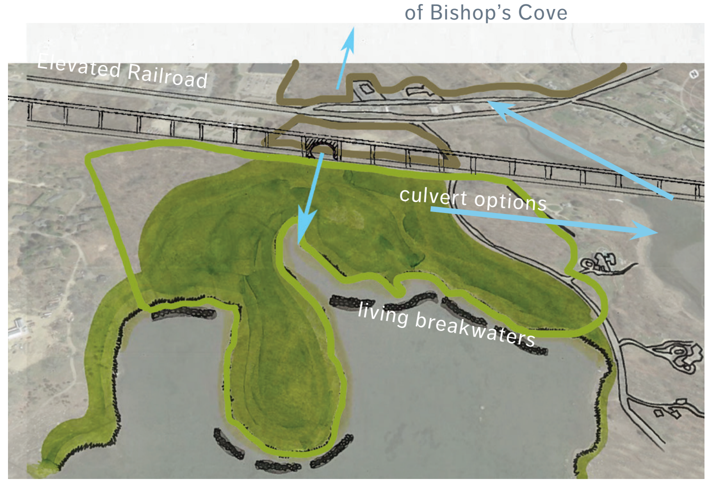
Living breakwaters could be implemented along the foot of Cottrell Marsh to increase protections to the shoreline and maintain the integrity of this important ecosystem. Enhancing the marine ecosystem with new shellfish habitats in this area may also help to further support the shoreline birds known to inhabit the area.

CREATE RECREATIONAL SPACE

A raised boardwalk through the wetlands park could create recreational and educational opportunities for the community, in line with principles laid out in *Stonington's Open Space Plan* (2015).

Blue arrows indicate two suggested locations for culverts to reconnect Cottrell Marsh to the inland wetlands of Bishop's Cove





Modifying infrastructure would be necessary in order to re-establish the hydrological connection between the different wetlands areas. One option may be to remove the impoundment created by the Amtrak line and creating a culvert underneath the railroad line and Route 1. This option could be incorporated into the plan to raise the railroad line, as recommended by the *Coastal Resilience Plan* (2017). The project to raise the Amtrak line was one of the highest priority suggestions made in the Plan for the town of Mystic.

Another option may be to create a culvert to connect Cottrell Marsh to the Stonington River, which is connected to the Bishop's Cove area via existing culverts beneath the railroad and highway. However, these culverts will also need to be enlarged to accommodate future higher tidal elevations.Both options necessitate working with private land owners and modifying infrastructure for increased future water levels.

Mason’s Island

Strengthening protections of existing tidal marshes and siting restoration interventions along the southwestern point of Mason’s Island encompassing Ram’s Point may assist the tidal wetland complex to expand in pace with sea level rise and provide increased buffering capacity against storm surges for the surrounding residential community. Living shoreline projects could be designed in the areas surrounding Clam Point, Mud Cove, and Bass Strait by working with local residents or land acquisition to increase the size of the conservation easement.

As a barrier island, Mason’s Island protects the inner harbor from exposure to the open ocean. Landforms such as Ram’s Point and Clam Point that extend along the southwest of the island, help to obstruct the southerly and westerly winds that predominate in this area (Weather Spark). Prioritizing preservation of the landforms can help to maintain their protective capacities, benefiting not only the residents of Mason’s Island, but the larger community surrounding Mystic Harbor.

Two protected open space areas are located along this southwest stretch of the island, Ram’s Point Preserve and the Great Marsh conservation easement, both managed by Avalonia Land Conservancy. There are a number of key connecting parcels situated between these open spaces which will be strongly affected by sea level rise. Working with private land owners to site coastal interventions in these locations is essential to preserving these landforms from inundation from future sea level rise.

SITE DETAILS

Owner(s):

- Avalonia Land Conservancy
- Private Land Owners

APPROACH METHODOLOGY

Enhance Marshes

Implement Breakwaters

Work with Landowners

Extend Trail Network

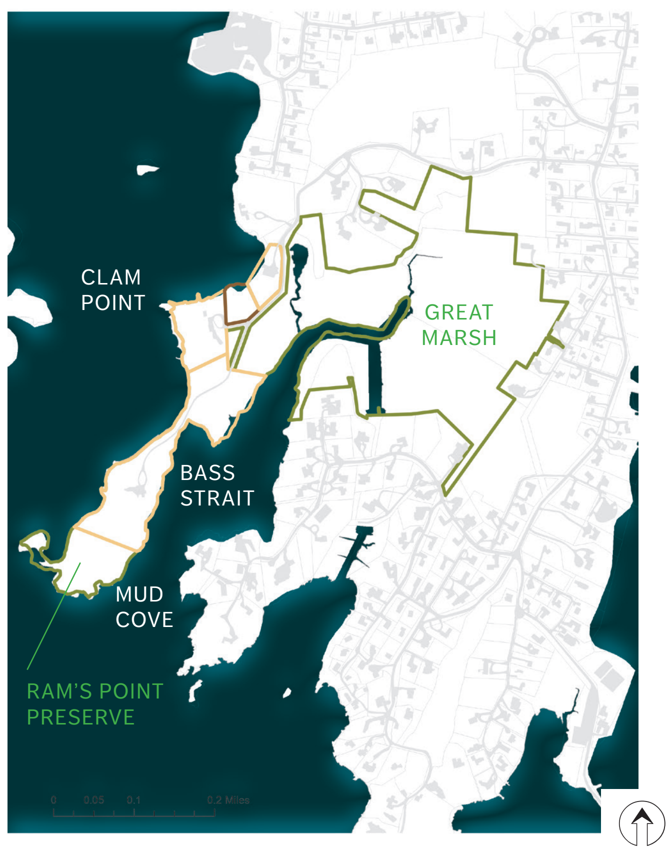
Create Kayaking Park

SPECIAL CONSIDERATIONS

Private Ownership

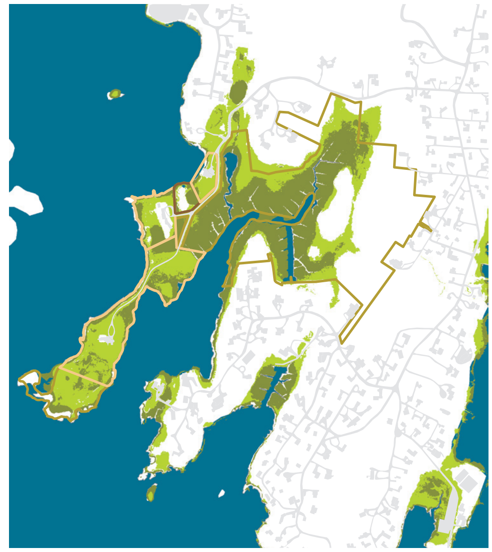
Erosion/Subsidence

Access/Local Traffic



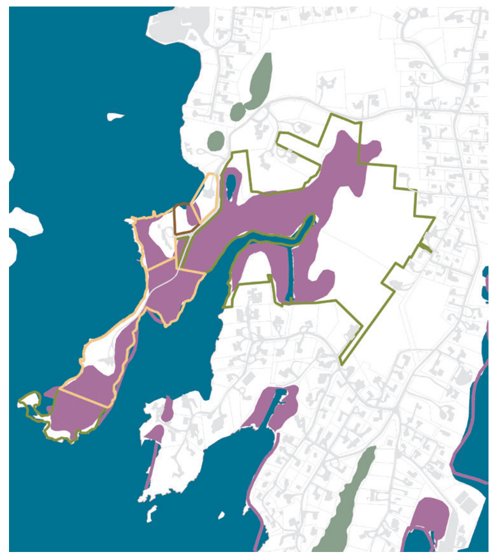
MARSH SUITABILITY MODEL

Results of the marsh suitability model in this area indicates significant potential marsh expansion on Clam Point and Ram's Point, correlating with the projected Sea Level Rise in the area.



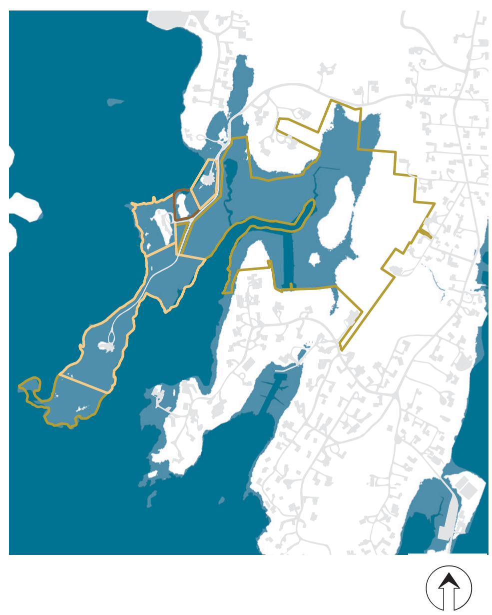
LAND USE

Current land use practice indicates that the key connecting parcels between these protected open spaces are residential properties and one privately owned vacant lot with extensive tidal wetlands.



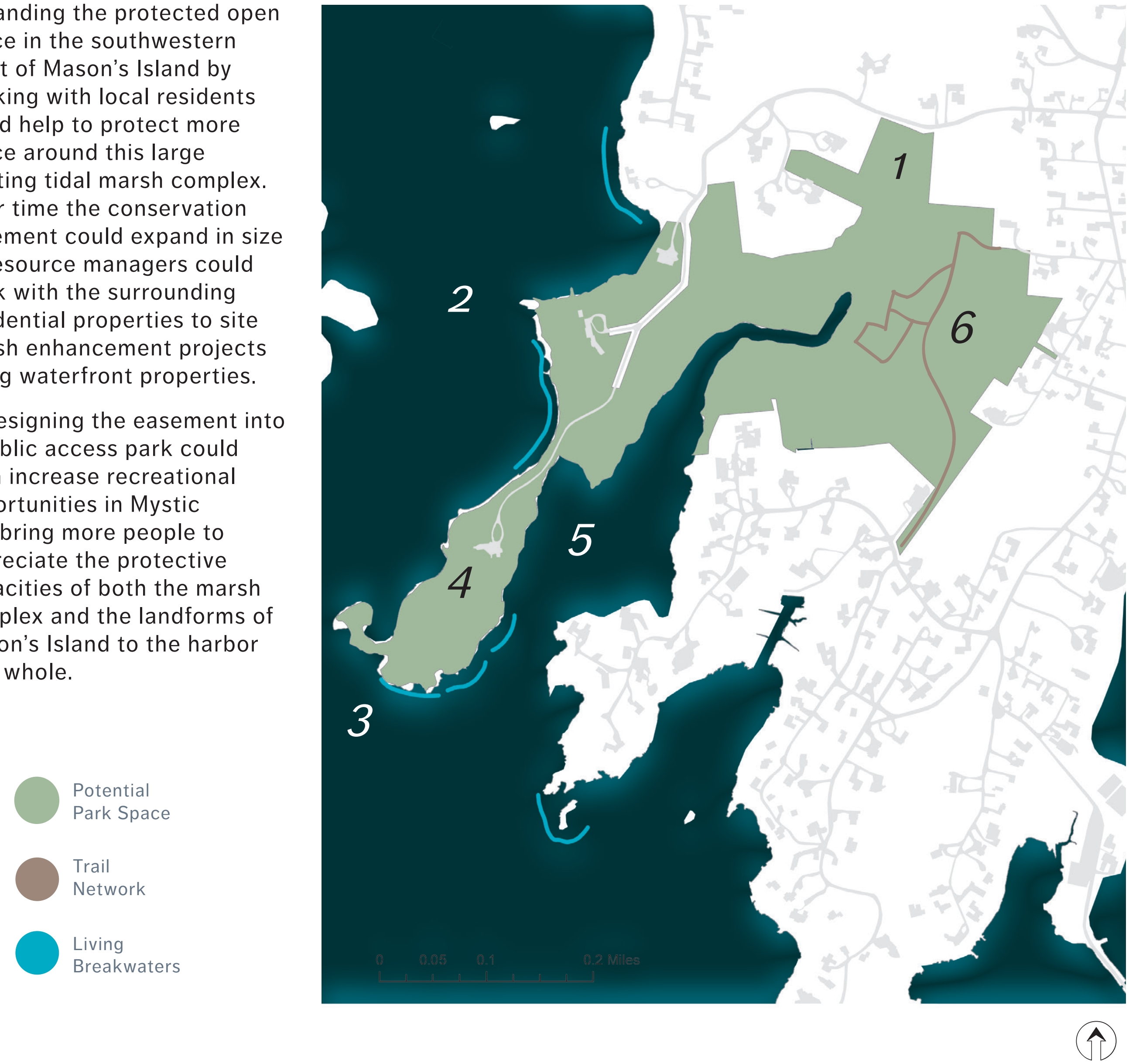
SEA LEVEL RISE PROJECTIONS 2050

A closer look at sea level rise projections in this area indicate widespread inundation by daily high tides in the future. This suggests the need to work with private land owners to preserve property or otherwise address this future changing condition.



Expanding the protected open space in the southwestern point of Mason's Island by working with local residents could help to protect more space around this large existing tidal marsh complex. Over time the conservation easement could expand in size or resource managers could work with the surrounding residential properties to site marsh enhancement projects along waterfront properties.

Redesigning the easement into a public access park could both increase recreational opportunities in Mystic and bring more people to appreciate the protective capacities of both the marsh complex and the landforms of Mason's Island to the harbor as a whole.



1 ENTRANCE TO BOARDWALK AND BIKE PARKING AREA

A higher elevation area off of School House road may offer space for a park entrance with a small number of car parking spots to encourage bike transportation and limit increasing car traffic to the neighborhood.

2 LIVING BREAKWATERS

Structural components designed to provide added protections to the landforms of Clam and Ram Points can help to address the higher exposure to wave energy in these areas.

3 POTENTIAL MARSH ENHANCEMENT

Ram's Point Preserve may offer space for a marsh restoration project to address recent erosion that has resulted in a loss of marsh area on the western side of Ram's Point.

4 MANAGE MARSH WITH RESIDENTIAL PROPERTIES

The town could work with private land owners to develop living shoreline projects along vulnerable stretches of the coastline of Ram's Point and Clam Point. Landscape management plans could be created to better support marsh expansion and preserve this important landform.

5 KAYAKING PARK

Picnic spaces created within Ram's Point Preserve, only accessible by water, could create a "kayaking park" to encourage water-based recreation and get more people to interact with the tidal marsh habitat to learn and appreciate its dynamic beauty. Collaboration with local recreational groups and kayaking outfitters in town may help generate excitement and buy in for the creation of this new local destination.

6 TRAIL MANAGEMENT & PARK DESIGN

There are a number of trails within the higher-elevation, eastern side of the easement that are accessible to nearby residents. Public access to this trail network could be improved by developing a public access trail map and designing a clear entrance to the park with parking. This could open the space to the larger community and bring greater appreciation for this community asset. Educational signage and outdoor learning lab spaces could be incorporated into the space to teach about coastal resilience and the many ecological services offered by tidal marshes.

CONSIDERATIONS FOR WETLAND PARKS

There are a number of challenges to establishing wetland parks. The following challenges and potential solutions were identified through conversations with local planners, informed by lessons learned in case studies, and feedback from community meetings that were part of this project. The primary concerns revolve around ownership of lands with existing wetlands or in areas of projected marsh advancement, educating the community on vulnerability, and finding funding for such projects.

CHALLENGES	POTENTIAL SOLUTIONS
Cost of land acquisition and/ or developing conservation easements.	Offer incentives for private land owners to develop easements in areas with wetland or sell land at discounted cost; work with local land trusts, state and federal conservation grants.
Developing community buy-in and consensus.	Develop educational workshops on the use of tidal wetlands as coastal protection; Community consensus building workshops and park master plans.
Funding and workforce for management of newly acquired and/or protected park spaces	Work with local conservation and recreational groups to find volunteers; allocating a small budget for management.
Management of invasive species, viewshed concerns related to phragmites growth.	Ensure proper drainage of tidal flow areas, analyze upland storm flows into properties to avoid stagnant water that offers conditions for Phagmites growth; develop maintenance plans.
Need to determine if intended park uses and living shoreline projects are allowed in the language of current property management plans and/or conservation agreements.	Work with land conservancy groups to make amendments to management plans and conservation restriction agreements to allow restoration work and trail building.
Existing development within proposed expanded wetland buffers.	Develop incentives with property owners to create more marsh-friendly landscaping and modify impervious surfaces where possible.

Protection Options

TOOLS

Increased wetland protections

Conservation easements

Trail easements

Land Acquisition

Municipalities have a number of options for creating wetland parks depending on funding resources, protection priorities, and land ownership of a given site. When possible, working with land trusts to acquire parcels for conservation may be the most straight-forward solution. However, where funding is limited, reaching out to private owners of vacant lots to establish conservation easements within unbuildable areas with or adjacent to existing wetlands may be an accessible first step in the process. Increasing wetland protections, as outlined in the wetland connectivity strategy through the use of buffers, can also protect land for parks by preventing future development within and near valuable wetland areas. With regulatory protections established, private property owners may be more inclined to develop trail easements with the wetland areas that may be used to develop recreational trail networks and parks. While issues with development rights may arise, incentives can be developed for owners willing to comply to new regulations. Private property owners of currently unbuildable lots may be more inclined to sell to land trusts, while neighboring properties may see benefits of potential increased property values from new proximity to park lands.

Community Engagement

COMMUNITY GROUPS

Clean Up Sound and Harbors (CUSH)

Avalonia Land Conservancy

Stonington Town Land Trust

Local schools and universities

Incorporating community engagement is essential for building community-scale coastal resilience. This component of the design process becomes even more essential when envisioning changes to existing open space and acquisition of land for wetland parks. Overall engaging the community in the process can provide valuable insights on stakeholder vision that can result in more site-specific designs that are meaningful to the people who live there. Initiating interactive design events like public charettes to discuss goals and desired amenities can build community support by rallying cooperation around coastal resilience and pride of place. These events can also result in greater volunteer support that can help offset other project costs. People are more willing to donate their time and appreciate parks if they are engaged in the planning process and can give input about design decisions, fostering a sense of ownership.

Working with local community groups such as environmental and recreation groups can assist with outreach and education on the benefits of proposed projects, helping to garner community buy-in. Engaging community members who are already using these recreational spaces may also provide experience-based information for ground-truthing analyses and design questions.

Even after the completion of projects, community groups can help with monitoring and management of sites. Volunteers can be rallied under the charge of citizen science, inventoring plants and animals helping to monitor the overall health of these ecosystems. Parks can become spaces for school outdoor education and site monitoring projects developed in partnership with local colleges and universities can provide support for seasonal management, helping to ensure the long term success of living shoreline projects.

Limitations and Future Considerations

Climate change presents a unique and timely challenge for coastal communities. While proactive, immediate interventions are integral to building a foundation for resilience, the compounding risks of sea level rise bring to question whether current adaptations will become obsolete, and, if so, how soon.

As sea levels continue to rise, there is a likely future in which interventions that require a greater change in environmental conditions will be necessary. These changes include, but are not limited to, land use change through zoning amendments, managed migration, and a re-evaluation of the community's connection to the coastline.

The preceding recommendations are grounded in the environmental conditions of Mystic; the concepts outlined are applicable in the near future with the least change in land use, harbor use, and general patterns possible. Yet it is important to understand the potential limitations of these recommendations. The preceding recommendations offer a foundation for coastal resilience but the plan is incomplete without acknowledgment of necessary considerations for future managed migration and a fundamental reconsidering of land use and coastal lifestyles.

The Town of Stonington and community of Mystic Village should consider the following interventions for enhanced coastal resilience:

> ZONING AMENDMENTS, for example, the removation of all variances and requiring a consistent 100-foot coastal property setbacks in line with policy outlined in Connecticut's Coastal Management Act. Amendments may also include increased freeboard elevation requirements and adaptations to building codes.

> TOWN PRE-VISIONING, an interactive process of how a municipality can plan for disaster recovery prior to a natural disaster occurring. This approach can be most effective as a participatory and educational process that engages the community to envision what they want for the future if there is the need to rebuild after damages from a storm. By planning ahead, towns can be ready to build smarter with a shared community vision after a major storm and effectively decrease the potential for repeated damage. Consensus building and collaboration between various municipal departments is foundational to the process of town pre-visioning. Often this process involves inventorying existing resilience regulations and developing an agreement on priorities that can then be translated into an action plan for the future.

> MANAGED MIGRATION, relocation of development to areas outside the floodzone. Suggestions made in the zoning analysis such as utilizing floating redevelopment zone to incentivize and facilitate a transition in development patterns may assist this process.

APPENDIX SECTION

The Office of Long Island Sound Programs (OLISP) offers the following model regulation language that establishes a uniform 100-foot vegetated buffer adjacent to all tidal wetlands. Prior to adoption, this regulation may be tailored to the specific conditions and concerns in your municipality.

A resource protection buffer of 100 feet shall be established along the upland edge of any tidal wetland as defined by Connecticut General Statutes section 22a-29(2). The width of the buffer shall be measured inland from the upland edge of the tidal wetlands except in the case of wetlands bordered by slopes greater than 25% in which case the buffer shall be measured inland from the top of the slope.

The following uses and activities are prohibited within the buffer:

1. New building construction that increases the building area or footprint including minor additions to existing buildings;

2. Detached accessory buildings such as garages and sheds;

3. Pools, tennis courts, patios, terraces;

4. Driveways, parking areas;

5. Other impervious surfaces;

6. Seawalls, bulkheads, retaining walls, landscaping walls or similar structures;

7. Grading, excavation or filling, including the construction of new septic systems;

8. Land clearing, except for minor clearing to allow for appropriate landscaping or the provision of acceptable access as noted below;

9. Dumping of lawn clippings and other wastes; and

10. The application of fertilizers and/or pesticides except when necessary to address a public health issue as determined by the local health official and/or the State Department of Health Services or to control an infestation of invasive vegetative species if authorized by the local conservation commission.

The following uses and activities, although not expressly prohibited, are discouraged

within the buffer area:

1. The establishment of new lawn areas;

2. Extensive clearing or pruning. Minimal clearing to provide views may be allowed; however, to maximize the effectiveness of the buffer, pruning should only be done to the extent necessary to clear a view lane and in a manner that maintains the understory and, if forested, the canopy of the buffer area, i.e., no pruning should be conducted within three feet of the ground to protect the understory and, if wooded, no pruning should occur above 9 feet above the ground to protect the canopy.

The following uses and activities are permitted and/or encouraged within the buffer area:

1. Preservation of existing native vegetation, including shrubs and trees;

2. Removal of invasive species and replacement with native species;

3. Elimination and/or minimization of mowing to encourage a variety of native species including shrubs and trees;

4. Planting of native vegetation; and.

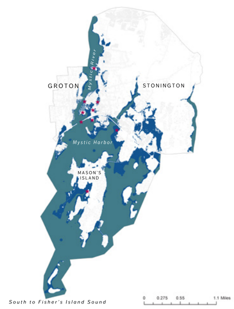
5. Provision of passive recreational opportunities, including the provision of public access where appropriate. However, such uses should be provided at an appropriate scale so as not to significantly diminish the performance of the buffer as a measure to protect tidal wetlands from disturbance and/or degradation. For larger projects, passive recreation components within a tidal wetlands buffer could include provision of walking trails, benches, small-scale picnic areas, and associated amenities.

This regulation does not prohibit the continued use, reconstruction or renovation of any septic disposal system, building, or other improvement in existence on the effective date of the regulation nor does it prohibit the construction of new improvements necessary for the function of water-dependent uses as defined by Connecticut General Statutes section 22a-93(16) except when those improvements can functionally be located outside of the buffer area.

Variance of this regulation is strongly discouraged. Exceptions may be made only in those instances where strict adherence would render a parcel unusable. In those cases, the minimum variance necessary to make the parcel usable should be the maximum variance considered.

APPENDIX II: MAP SOURCES

Data used in the production of this report came from various sources outlined on the following pages. Many of the map layers were processed and combined in different ways to assist in assessing vulnerability of the project area and in developing the living shoreline suitability analysis process.



Sea Level Rise 2050 Map

Sea level rise for 2050 was mapped with community-identified assets to show vulnerbality from rising ocean levels within the project area and for comparison to the storm surge scenarios on the following pages. The project designs interventions for both sea level rise and storm surges.

Layers Used: modified 2016 USGS CoNED Topobathymetric Model (1887 - 2016): New England; 2012 Impervious Surfaces, Buildings; Community-Identified Asset point layer created from community meeting feedback; Connecticut Named Waterbody Polygon

Source: Shoreline Team; NOAA Office for Coastal Management, Digital Coast Data Viewer (Elevation); CT ECO; CT DEEP

Pages: 13

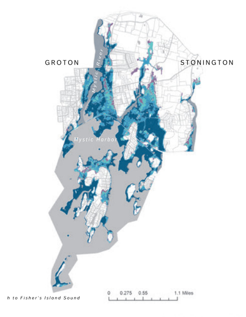
1% and 0.1% Storm Inundation Maps

Storm surge inundation was mapped for the project area for the years current to 2100 to evaluate projections of land, historic properties, and property values affected over time.

Layers Used: 2013, 2030, 2050, 2070 Storm Probability of 1% and 0.1% storm; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Woods Hole Group; Stonington Planning Department; CT ECO; CT DEEP

Pages: 16



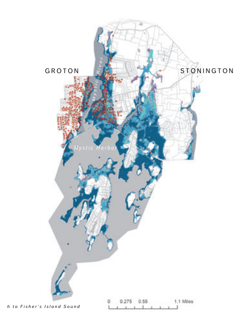
Property at Risk Map

Property affected by inundation from 1% storm surge in 2050 including sea level rise was mapped to evaluate the extent of buildings and accompanying property values at risk from damage.

Layers Used: Depth of Inundation 1% storm in 2050 Layer; Stonington Parcels; Connecticut Named Waterbody Polygon

Source: Woods Hole Group; Stonington Planning Department; CT DEEP

Pages: 17



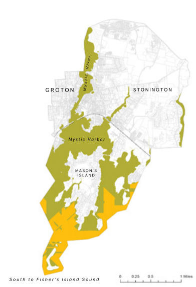
Historic Buildings at Risk Map

Probablity map of depth of inundation for 1% storm surge was mapped for the project area to evaluate potential impacts to historic properties and property values affected over time.

Layers Used: Historic Buildings; Inundation 1% storm raster; Stonington Parcels; Connecticut Named Waterbody Polygon

Source: Stonington Planning Department; Woods Hole Group; CT DEEP

Pages: 19



Fetch Map

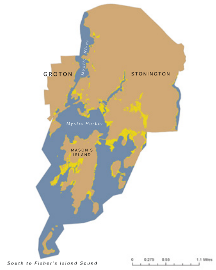
A fetch GIS-model was used to assess the wave energy within Fisher's Island Sound then clipped to look specifically at the project area.

Layers: Fetch data; 2012 Impervious Surface, buildings and roads

Source: Shoreline Team; CT ECO

Pages: 41

MAP SOURCES



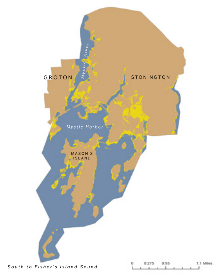
TIDAL ZONE: CURRENT CONDITIONS MAP

Tidal zone was mapped for the current conditions as part of the shoreline criteria for the marsh and living breakwaters suitability models.

Layers Used: 2016 USGS CoNED Topobathymetric Model (1887 - 2016): New England; Connecticut Named Waterbody Polygon

Source: Shoreline Team; NOAA Office for Coastal Management, Digital Coast Data Viewer (Elevation); tidal data was obtained from NOAA station located in Mystic Harbor, CT DEEP

Pages: 45



TIDAL ZONE: 2050 MAP

Tidal zone for 2050 was mapped as part of the shoreline criteria for the marsh and living breakwaters suitability models.

Layers Used: 2016 USGS CoNED Topobathymetric Model (1887 - 2016): New England; Connecticut Named Waterbody Polygon

Source: Shoreline Team; NOAA Office for Coastal Management, Digital Coast Data Viewer (Elevation); tidal data was obtained from NOAA station located in Mystic Harbor; CT DEEP

Page: 45

LANDWARD SLOPES MAP

Landward slopes were mapped as part of the shoreline criteria for the marsh and living breakwaters suitability models.

Layers Used: 2016 USGS CoNED Topobathymetric Model (1887 - 2016): New England; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Shoreline Team; NOAA Office for Coastal Management, Digital Coast Data Viewer (Elevation); CT ECO; CT DEEP

Pages: 47

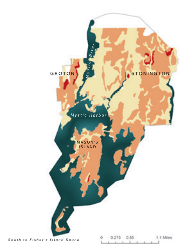
BATHYMETRIC SLOPES MAP

Bathymetric slopes were mapped as part of the shoreline criteria for the marsh and living breakwaters suitability models.

Layers Used: 2016 USGS CoNED Topobathymetric Model (1887 - 2016): New England; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Shoreline Team; NOAA Office for Coastal Management, Digital Coast Data Viewer (Elevation)); CT ECO; CT DEEP

Pages: 49



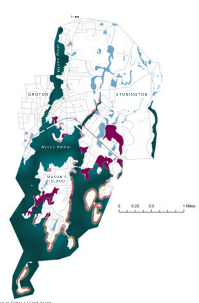
ERODIBILITY MAP

Erodibility was mapped as part of the shoreline criteria for the marsh and living breakwaters suitability models.

Layers Used: Soils layer; Connecticut Named Waterbody Polygon

Source: Shoreline Team; USDA Natural Resource Conservation Service; CT DEEP

Pages: 51



WETLAND TYPES MAP

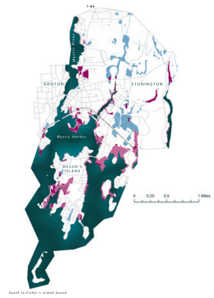
Wetlands were mapped part of the existing conditions relevant to the marsh and living breakwaters suitability models.

Layers Used: National Wetlands Inventory; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: US Fish and Wildlife Services; CT DEEP; CT ECO

Pages: 53

MAP SOURCES



TIDAL WETLAND LOSS MAP

Wetland loss was analyzed to contextualize the resource management and historic development trends in the project area.

Layers Used: Tidal Wetlands 1970's; Tidal Wetlands 1990's; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: US Fish and Wildlife Services; CT ECO; CT DEEP

Pages: 55

COASTAL STRUCTURES MAP

Shoreline structures were mapped as part of the existing conditions relevant to the marsh and living breakwaters suitability models.

Layers Used: SLAMM V2 Connecticut Coastal Structures 2015; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: CT DEEP; CT ECO

Pages: 59

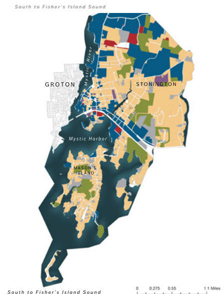
HARBOR CIRCULATION MAP

Harbor circulation was mapped as part of the existing conditions relevant to the marsh and living breakwaters suitability models.

Layers Used: Strava Heat Map geolocated to the project area; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Strava; CT ECO; CT DEEP

Pages: 62



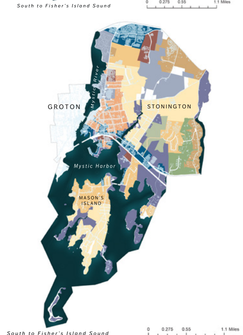
LAND USE MAP

Land use was mapped to determine development patterns relevant to siting coastal interventions in the project area.

Layers Used: Stonington Parcels; Connecticut Named Waterbody Polygon

Source: Stonington Planning Department; CT DEEP

Pages: 65



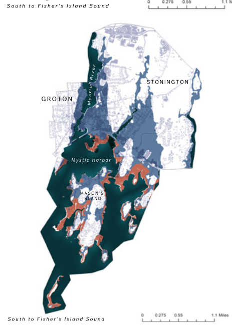
ZONING DISTRICTS & DENSITY MAP

Zoning was mapped to gain understanding of current and potential future development patterns, and to visualize current wetland protections by zoning district within the project area.

Layers Used: Stonington Parcels; 2012 Impervious Surfaces, buildings and roads; Connecticut Named Waterbody Polygon

Source: Stonington Planning Department; CT ECO; CT DEEP

Pages: 67



FEMA FLOOD ZONES MAP

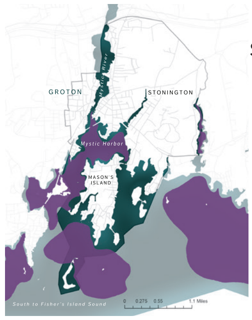
The Coastal V and A zones were mapped to determine the vulnerability of the project area and the location of higher-density development zones in relation to storm surge floodplains.

Layers Used: 2013 FEMA Flood Zones; 2012 Impervious Surfaces, buildings and roads; Connecticut Named Waterbody Polygon

Source: Stonington Planning Department; CT ECO; CT DEEP

Pages: 69

MAP SOURCES



SHELLFISH SPECIES MAP

The species of shellfish were mapped to determine areas where shellfish populations have decline, specifically oysters and mussels (species that could aggregate on living breakwaters)

Layers Used: Shellfish Species; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: CT DEEP; CT ECO

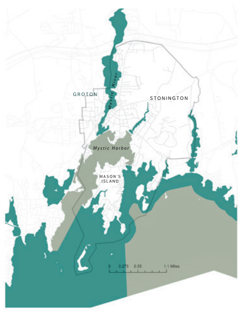
Pages: 71

SHELLFISH COMMERCIAL HARVESTING AREAS MAP

Layers Used: Recreational Shellfishing Beds; Commercial Shellfishing Beds; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Connecticut Bureau of Aquaculture; CT ECO; CT DEEP

Pages: 73



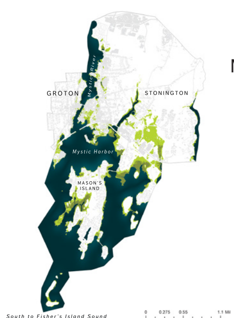
IMPAIRED WATERS MAP

Water quality was mapped for the project area to assess suitable habitat conditions for shellfish used in living shoreline techniques. Impaired waters were mapped within the project area to determine the location of pollutants that may negatively affect shellfish health and present challenges to the success of living breakwater interventions. The map displays areas where water quality do not comply with the Clean Water Act standards and do not support the consumption of shellfish.

Layers Used: Connecticut 305B Assessed Estuary 2016; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: CT DEEP; CT ECO

Pages: 75



MARSH SUITABLITY MODEL RESULTS MAP

Layers Used: Generated data; Impervious Surface, buildings and roads

Source: Shoreline Team; CT ECO

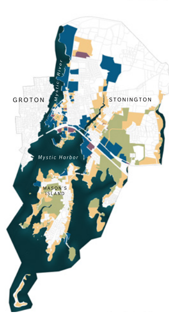
Pages: 83

AREAS OF CURRENT/FUTURE MARSH SUITABLITY: CORRELATION TO WETLANDS

Layers Used: Generated data; National Wetlands Inventory; Impervious Surface, buildings and roads

Source: Shoreline Team; CT DEEP; CT ECO

Pages: 85



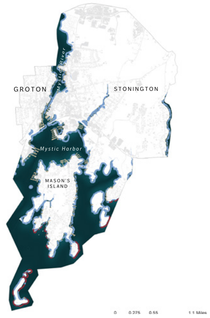
LAND USE OF PARCELS INTERSECTING THE MARSH MODEL MAP

Layers Used: Stonington Parcels; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Stonington Planning Department; CT ECO; CT DEEP

Pages: 85

MAP SOURCES



LIVING BREAKWATER SHORELINE CRITERIA SUMMARY MAP

Layers Used: Generated buffer data; SLAMM V2 Connecticut Coastal Structures 2015, docks and marinas; 2012 Impervious Surface, Roads; Connecticut Named Waterbody Polygon

Source: Shoreline Team; CT ECO; CT DEEP

Pages: 89

LIVING BREAKWATER EXISTING CONDITIONS SUMMARY MAP

Layers Used: Connecticut 305B Assessed Estuary 2016; 2012 Impervious Surface; Connecticut Named Waterbody Polygon

Source: Strava; Connecticut Bureau of Aquaculture; CT ECO; CT DEEP

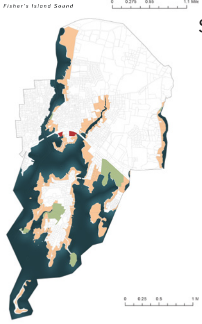
Pages: 91

SUGGESTED AREAS FOR LIVING BREAKWATERS MAP

Layers Used: Generated data; 2012 Impervious Surface; Connecticut Named Waterbody Polygon

Source: Shoreline Team; CT ECO; CT DEEP

Pages: 91



SHORELINE ACCESS MAP

Public vs private access to the shoreline was mapped to

Layers Used: Stonington Parcels; Protected Open Space Mapping (POSM; Connecticut Named Waterbody Polygon

Source: Town of Stonington Planning Department; CT DEEP

Pages: 134

APPENDIX III: GIS ANALYSES

VECTOR ANALYSIS

This is an outline of our analyses process. The following steps were taken to evaluate vulnerablity and potential impacts to land area, historic structures, and property value within the project area. Storm surge scenario data used was developed by the Woods Hole Group. These raster-based data layers were converted to polygon, then used in the vector analysis outlined below. Similarly, the sea level rise raster created from a topobathymetric LiDAR DEM was converted to polygon to be used in the following vector analysis. For current 1% and 0.1% storm surge scenarios, vector-based FEMA data was used.

Valuation of Property Affected by Sea Level Rise by 2050

Buildings affected by sea level rise/storm surge scenarios were determined then intersected by parcels to create a new layer of parcels with buildings affected by inundation. Property values affected by inundation were then determined using the attribute table of the new layer.

1. Buildings layer obtained from CT DEEP Impervious Surfaces data

2. Clip Buildings layer to Project Area

3. Vectorize sea level rise or storm surge layers using the Raster to Polygon (Spatial Analysis) tool

4. Use Select by Location tool, set Buildings layer as Target, vector sea level rise/storm surge layer as Source, run as Intersect, name Buildings Affected

5. Export Data to create new layer with selected buildings

6. Parcel data layer obtained from municipal planning department. The attribute table for this data layer includes assessor's data on market values and assessed value per property. If the parcel data layer does not include assessor's data, create an excel spreadsheet, save as ".csv" file, Add Data, and Join the table

7. Clip Parcels layer to the Project Area

8. Use Select by Location tool, set Parcels layer as Target, Buildings Affected as Source, run as Intersect

9. Export Data to create new layer with selected parcels

10. Use Statistics tool on the "assessed value" value field within the attributes table. (The correct value field was verified with Stonington's Planning Department and Assessor's Office)

Historic Buildings Affected by Sea Level Rise/Storm Surge Scenarios

1. Historic Structures data layer obtained from Stonington Planning Department

2. Vectorize sea level rise or storm surge layers using the Raster to Polygon (Spatial Analysis) tool

3. Use Select by Location tool, set Historic Structures layer as Target, vector sea level rise/storm surge layer as Source, run as Intersect

4. Use Statistics tool on the area or similar value field within the attributes table. Use the Count to determine number of historic buildings affected by inundation scenarios

Percentage Land Affected by Sea Level Rise/Storm Surges Scenarios

A similar process was used for sea level rise data alone for the year 2050 and storm surges (1% and 0.1% storms for the following years: 2019, 2030, 2050, 2070, 2100).

1. Parcel data layer obtained from municipal planning department.

2. Vectorize sea level rise or storm surge layers using the Raster to Polygon (Spatial Analysis) tool

3. Use Clip (Geoprocessing) tool: set Parcel layer as input features, vector sea level rise/storm surge as clip features, and create new output feature

4. In the attribute table of the new clipped data layer, create a new value field called "Area" using long integer

5. Right click on the Area value field, use Calculate Geometry to calculate the area affected by inundation within each parcels

6. Right click on the Area value field, use Statistics to determine the sum of the column

APPENDIX III: GIS ANALYSES

RASTER ANALYSIS

GIS models were created to determine areas suitable for marsh enhancement/creation and living breakwaters techniques based on shoreline criteria.

Three models were made in total:

1. Marsh Suitability Model for current conditions
2. Marsh Suitability Model for 2050 (SLR of 20")
3. Living Breakwaters Suitability Model

The initial process was similar for all three of these models.

Step 1: Identify the most relevant shoreline criteria

Step 2: Classify these layers to the ranges established in the Shoreline Criteria Value Ranges Table (found on p. 39 in the Analysis Section)

Step 3: Reclassify these layers to a binary for the given model.

Step 4: Use the Weighted Sum tool to combine the reclassified layers. Areas with the highest score represent areas where all the desired criteria ranges are met.

CLASSIFY

Fetch

1. A fetch model developed by David Finlayson, of the USGS Pacific Science Center, was used to run the analysis. This tool operates as an ArcGIS toolbox model. The tool was downloaded from the Upper Midwest Environmental Sciences Center website (umesc.usgs.gov/management/dss/wind_fetch_wave_models_2012update.html)
2. Artifical boundaries were added to the topobathy LiDAR to contain "unbound reaches" ie. areas that are exposed to the open ocean and cannot be determined by the model. Artifical boundaries were made by creating a new layer, adding polygon was then converted to raster and merged with the topobathy layer using the Mosaic to New Raster tool. The resulting raster was set as the land raster for the fetch tool.
3. A table of wind direction in degrees was created and added to the ArcMap file as a ".csv" and set as the wind direction/weighting percent list in the fetch tool.
4. The fetch tool was set was used, with the calculation method set to "single"
5. Results were then classified into 3 classes: 1, 5, highest value

Tidal Zone

1. NOAA Topobathy LiDAR layer
2. Classify into 3 classes: 0, 0.908, and the highest value (MLLW = 0, MHHW = 0.908 m)

Landward Slopes

1. NOAA Topobathy LiDAR layer
2. Extract by Value, Value > MLLW
3. Use Slope (Spatial Analyst) tool
4. Slope ranges in percentage were converted to degrees to use in the GIS slope tool (for greater accuracey)
5. Classify into 3 classes: 3.43, 11.31, and the highest value (ex: for the project area 35)

Bathymetric Slope

1. NOAA Topobathy LiDAR layer
2. Extract by Value, Value < MLLW
3. Use Slope (Spatial Analyst) tool
4. Slope ranges in percentage were converted to degrees to use in the GIS slope tool (for greater accuracy)
5. Classify into 3 classes: 3.43, 11.31, and the highest value (ex: for us 35)

Erodibility

1. USGS Soil data layer
2. Source k-factor data from USGS Web Soil Survey
3. Create excel spreadsheet with k-factor data for each soil MUKEY item, and create column ranking the erosion susceptiblity based on the following ranges of k-factor:

    Low: Less than 0.2

    Moderate: between 0.2-0.4

    High: Greater than 0.4

4. Save spreadsheet as ".csv" file

4. Add Data, Join to attribute table of soil layer

5. Use Merge (Geoprocessing) tool, merge by k-factor

MODELS

Marsh Suitablity Model

An automated model was created to reclassify into binary and combine the following layers with the Weighted Sum (Spatial Analysis) tool:

-Tidal Zone: Reclassify intertidal zone 0-0.908 to 1, all other ranges to 0

-Land Slopes: Reclassify low slopes range 0-3.43 to 1, all other ranges to 0

-Erosion Susceptiblity: Manually set 2 classes: low and moderate erosion 0-0.4, 0.4 to highest value; Reclassify 0-0.4 to 1, greater than 0.4 range to 0

*set missing data to NoData

Living Breakwaters Suitablity Model

An automated model was created to reclassify into binary and combine the following layers with the Weighted Sum (Spatial Analysis) tool:

-Fetch: Reclassify 0-1 mile to 1, all other ranges to 0

-Tidal Zone: Reclassify land below MLLW to 1, all other ranges to 0

-Bathymetric Slopes: Reclassify 0-3.43 range to 1, all other ranges to 0

-Erosion Susceptiblity: Manually set 2 classes: 0-0.4, 0.4 to highest value; Reclassify 0-0.4 to 1, greater than 0.4 range to 0

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Mystic is a historic village along the southeast coast of Connecticut. As a coastal community, the village is vulnerable to the negative impacts of sea level rise and storm surge inundation. *Shoreline Interventions for Coastal Resilience* explores new ideas to improve protection where land meets water and provides the community with tools to envision these new ideas in situ.

The report analyzes potential locations for living shoreline techniques, specifically breakwaters and marsh creation/enhancement, based on shoreline criteria and environmental conditions. The proposed shoreline interventions are appropriate for particular residential, non-residential, and open space conditions in Mystic, yet they may be a model for other coastal communities in the northeast.

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