

Building on Shifting Sands: Shoreline Stabilization in the Commonwealth of Massachusetts

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Abstract

This thesis explores coastal property owners' role in managing erosion along the coastline of Massachusetts. Property owners often attempt to protect the shoreline along their property from change, leading to shoreline stabilization techniques. Stabilization practices vary; however, the traditional approach is shoreline hardening, which has led to roughly 27% of Massachusetts's coastline becoming hardened (Coastal Erosion Commission 2015). Although shoreline hardening has become a common practice, alternative techniques have developed that focus on employing ecologically based approaches (Nature-Based Solutions) and relocating populations away from the shoreline to reduce risk (Managed Retreat). This thesis examines the impact of granting private ownership to the low water mark in the Commonwealth and that ownership influences shoreline stabilization practices. Additionally, this thesis explores the current regulatory landscape works to safeguard the environment from adverse impacts from shoreline modification. This thesis concludes with policy recommendations to reduce coastal hardening and increase the coastline's ability to adapt.

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Chapter 1: Introduction

Anyone that has ever made a sandcastle on the beach has considered ways to defend their “structure” from eroding into the ocean. Children crowd the coastline along the beaches of Massachusetts in the summer, their buckets and shovels in hand, building sandcastles vulnerable to the ocean and its destructive forces (Figure 1). If one were to observe this constructive play process, a few design strategies would include a seawall to defend the sandcastle structure from the inevitable surge of water that would approach its foundation as the tides change. This solution often consists of an engineered wall that temporarily blocks the effect of the coastal processes that would result in the sandcastle meeting its demise.



Figure 1. Young children designing a seawall on the Beach during the summer in the City of Boston (Boys and Girls Clubs of Boston 1969).

The seawall only protects the sandcastle in the short term; unable to protect the structure from overtopping, the wall will suffer when the tide turns. Eventually, the seawall designed to protect the castle will fail, and the sandcastle will be swept away into the ocean. Even as

children, we accept this reality and understand that there are consequences to building structures so close to the water.

Some of the children might re-design and adapt the next time they choose to build. A reasonable response for the sandcastle builder would be to construct their structure further away from the ocean to reduce the likelihood of destruction. This strategy is similar to a managed retreat, known as the “purposeful and coordinated movement of people and assets out of harm's way” (Siders 2019, 216). Additionally, the builder could adopt an alternative approach, building behind a wetland, which would help absorb wave action and slow the rate at which water re-enters the area. This strategy would be a nature-based solution, a practice that prioritizes working with the natural services an ecosystem can provide (Bilkovic et al. 2017).

Children who build a sandcastle on shifting sands quickly understand their coastal property's vulnerability, using a bucket and some sand to adapt their approach and protect their structure for the next changing tide. However, this soberingly simple life lesson learned by children each summer is only modeled by some coastal property owners who utilize the coastline. “Man [sic. People have] has been simultaneously awed by the sea and attracted by its shores. He [sic. They have] has consistently attempted to protect his (sic. their) settlements against the onslaughts of the sea” (Charlier, Chaineux, and Morcos 2005, 79). Coastal property owners in the Commonwealth of Massachusetts face a similar scenario to the sandcastle builder. They are acutely aware of their property's risks, including property loss, flooding, erosion, and costly storm damage (Bin, Kruse, and Landry, 2008). However, development and redevelopment along the coast continue regardless of how many coastal properties are flooded and seawalls destroyed.

Historically, human civilizations have developed coastlines out of economic necessity due to the increasing demand for work and life near the coast (Charlier, Chaineux, and Morcos 2005). Coastal lands have long been attractive areas for settlement, as they often contained flat, productive lands with abundant access to water, allowing for trade and commerce to develop (Griggs 2017). Human impact on the coastline included grazing dune vegetation by domesticated animals on a relatively small scale (Griggs 2017). However, Gary Griggs notes, “The footprints of the early humans who occupied and settled the coast were quite modest compared to today’s impacts” (Griggs 2017, 9). The damage that has occurred to coastlines over the past 150 years is vastly different due to increased population numbers, machinery, and technological advances (Griggs 2017).

Coastlines change in response to human impacts and natural processes (Griggs 2017). A coastline is where the land meets the sea, a constantly shifting region due to the effects of wave action, tides, sediment movement, and weather. A coastline can look entirely different from one season to the next due to human influence or a winter storm (Oertel 2005). It can be built up with the accretion of sand in the summer or destroyed with the erosion of sand in the winter. The coastline is often viewed in terms of its coastal geography; however, it is essential to note that it is also a vulnerable ecosystem. There are unique abiotic and biotic components to each part of the system. Coastlines are more than just a boundary; they are a dynamic system that often contains natural and built elements that sometimes interact with one another in unique or surprising ways (Charlier, Chaineux, and Morcos 2005).

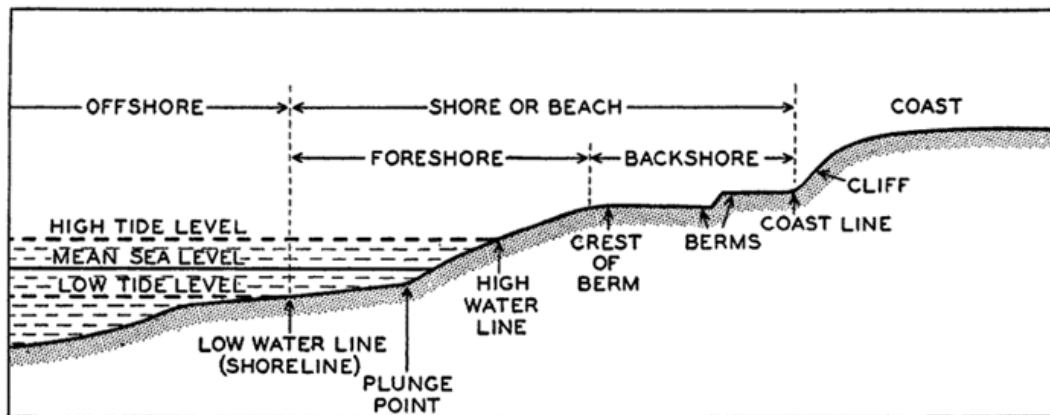


Figure 2. The components of the coastal zone, or where land meets the sea including the coastline and shoreline (Sverdrup 1942).

One component of this dynamic system is the shoreline, found between the tidelands' high and low water marks (Oertel 2005) (Figure 2). A shoreline marks where the land meets the water, and shifts with the elevation of the tide, meaning that the position of the shoreline at high tide is different from its position at low tide (Oertel 2005). "Sea level is generally defined as the elevation halfway between the high- and low-water elevations, and the generic 'shoreline' is meant to describe the line associated with sea level, rather with high or low tide. However, during the rise and fall of the tide, there are an infinite number of shorelines between high tide and low tide" (Oertel 2005, 325).

Coastlines are constantly changing; however, the rate of coastline change has been unprecedented in the last century, and the most dominant cause of long-term coastal change is climate change (Oertel 2005). Due to the Earth's changing climate, sea levels are rising, storms are becoming increasingly severe, and coastal erosion, properties, and infrastructure are threatened at an unprecedented rate. Sea-level rise contributes to the landward shift of shorelines, which contributes to an eroding line of where the shoreline once was (Oertel 2005). Shoreline retreat is the change from where the shoreline once was, and shore erosion or

“erosion” is used to describe the removal of volume from that section of shore (Oertel 2005, 326). Shoreline change models can reveal if a coastline is experiencing erosion, which is the loss of land or beach along the coast. The Massachusetts Office of Coastal Zone Management examined shoreline change in the Commonwealth. The Massachusetts Shoreline Change Project, launched in 1989, uses historical data to analyze shoreline trends, including erosion and accretion rates from the mid-1800s to 2009 (Commonwealth of Massachusetts. 2022).

The traditional approach to managing shoreline retreat along the coastal property is “shoreline stabilization,” a practice that uses multiple techniques to protect a shoreline from future or existing shoreline change (N.C. DEQ 2022; Pilkey and Cooper 2014). Stabilizing shorelines along the coast has conventionally come in the form of hardened structures such as breakwaters, bulkheads, and seawalls built parallel to the coastline, and their purpose is to protect the landward area from the sea (Charlier, Chaineux, and Morcos 2005). A hardened approach narrowly focuses on “holding the line” or protecting private property (Pilkey and Wright 1988; Neal, Bush, and Pilkey 2017). This approach does not consider the ecological or societal implications of hardening the shoreline; instead, it is narrowly focused on maintaining the shoreline in place over the near term. Hardened structures such as seawalls were built by private property owners to protect their coastal property, while the Federal Government managed only its property (Charlier, Chaineux, and Morcos 2005).

The prevalence of hardened shorelines increased substantially during the second half of the 20th century, particularly in the 1950s when there was a “rush to the shore” with increased infrastructure along the coast (Bilkovic et al. 2016; Pilkey and Wright 1988). The most extended period of shoreline development began following World War II as the utility of coastlines

shifted (United States Geological Survey 2012). During this time, advancements in transportation made travel to the coast easier and faster, causing the coastline to draw more visitors and infrastructure (Griggs 2017). The character of coastal towns changed from fishing infrastructure to oceanfront condominiums, and there was an increased need to protect commercial and residential development (Griggs 2017; United States Geological Survey 2012). An example from this period is when the United States Navy began closing military bases around the country, including 106 acres of oceanfront property along the Boston waterfront in 1974 (Boston Planning & Development Agency 2021). The site was transformed from a working waterfront to land maintained by the National Park Service (NPS) and land used to redevelop million-dollar condominiums (Christopher Stevens et al. 2005; Boston Planning & Development Agency 2021). By the 1970s, coastlines were 67% privately owned, with the Atlantic coast from Maine to Virginia being 87% privately owned (Lee 1999). In Massachusetts, the population increased by roughly 18% between 1950 and the 1970s, and up until the past two decades, much of the Massachusetts coastline consisted of working waterfront with undeveloped lands, which have since become available for new residential and commercial uses (Portman 2006; US Census Bureau 2021). Today, 75% of the population of Massachusetts lives along the coast, and the Commonwealth contains seventy-eight coastal communities along approximately 1,500 miles of coastline (Coastal Hazards Commission 2007; NOAA's Office for Coastal Management 2022). Due to the prevalence of shoreline hardening, roughly 27% of the exposed coastal shoreline in Massachusetts is hardened by some form of coastal protection (17% revetments/ 15% seawalls/bulkheads) (Coastal Erosion Commission 2015).

Although widely used, these hard stabilization practices have evolved slightly over time. They have resulted in increased erosion and damage to the land-sea connection, creating an ecological barrier between the land and the sea (Bilkovic et al. 2016). An increasing amount of academic literature on shoreline stabilization focuses on the harmful effects of creating a hardened barrier between shorelines and the sea (Gittman et al. 2015; Bilkovic et al. 2016; Griggs 2005; Hosseinzadeh et al. 2022; Jaramillo et al. 2021). Practices are evolving from engineered/gray/armored/hard stabilization practices to ecological/green/living/soft shoreline stabilization, and due to the negative impacts of hardening our shorelines, alternative practices have been developed, viewed as softer solutions (Gianou 2014; Mason, King, and Bernick 2020; Pontee et al. 2016). These practices are described as nature-based solutions (NBS), which seek to find a "greener" solution to stabilizing shorelines (Pontee et al. 2016). NBS, such as living shorelines, aims to “reduce damage and erosion while simultaneously providing ecosystem services to society, including food production, nutrient and sediment removal, and water quality improvement” (NOAA 2015). Nature-based solutions can restore shorelines, working with and enhancing ecosystem services rather than hardening the shoreline to buffer the impacts of the ocean (Bilkovic et al. 2016; Pontee et al. 2016). NBS includes beach nourishment, dune restoration, added vegetation, and bioengineered fiber rolls/ blanketing. These practices aim to work with nature; for example, bioengineered fiber rolls consisting of biodegradable materials hold sediment along a coastline, allowing for a stable environment for native plants such as *Spartina alterniflora* (Saltmarsh Cordgrass) to take hold (Bilkovic et al. 2016). Deeply anchored roots from plants such as *Spartina alterniflora* can help absorb wave energy during storms, holding shorelines in place. Lasting much longer after the manufactured fiber rolls have

disintegrated, these native plants help to naturalize the shoreline and improve the coastline's ability to adapt to change (Bilkovic et al. 2016). NBS enhance ecosystem services along the coast, improving water quality, plant and wildlife habitat, carbon sequestration, and erosion control (Chausson et al., 2020).

There is no one-size-fits-all solution when it comes to stabilizing shorelines. Structural approaches remain dominant even though practices have evolved to incorporate nature-based elements (Beasley and Dundas 2021). Regulations in the Commonwealth, such as the Coastal Zone Management Act and the Wetlands Protection Act, have been developed to balance anthropogenic impacts while preserving coastal resources through planning, public involvement, education, research, and resource management (Office for Coastal Management 2022). From these regulations, programs such as the Massachusetts Office of Coastal Zone Management Coastal Resilience Grant Program offer grants to reduce communities' vulnerability to coastal hazards (Office of Coastal Zone Management 2022), emphasizing NBS. However, programs such as these are limited in their ability to change the overall coastal landscape due to the role that coastal property owners play in selecting various shoreline stabilization methods in Massachusetts. In the Commonwealth, ownership of the coastline plays a critical role in influencing the likelihood of continued coastal hardening, which traces back to the land settlement patterns of the Commonwealth established during colonial times.

Before the colonization of the land known as the Commonwealth of Massachusetts, the land belonged to the Massachusetts, Wampanoag, Pennacook, Mahican (Stockbridge), Pocumtuck, and Nipmuck peoples (Galvin 2019). During the British colonization of the land, a royal charter was granted to the Massachusetts Bay Company to promote settlement of the

land, and the Company was the foundation of the government of the Massachusetts Bay Colony (Galvin 2019). Settlers established the coastline through industries such as cattle farming, salt marsh haying, shipbuilding, and commercial fishing (Keating 2015). Towns such as Marshfield, Massachusetts, were referred to by early English settlers as Green's Harbor, dubbed for the land and lush salt marshes woven between three rivers at the confluence of Massachusetts Bay (Town of Marshfield 1997).



Figure 3. Green Harbor in Marshfield, MA, located is on the South Shore of Massachusetts (Marinas.com 2023).

As the Commonwealth developed, the General Court enacted laws to manage the new citizens, property, and industries, including the Massachusetts Public Waterfront Act of the Massachusetts General Laws, which established ownership of the tidelands (Galvin 2019, Massachusetts General Laws, c. 91 et seq., hereinafter “Chapter 91”).

The tidelands are the lands between the mean high-water line (MHW) and the mean low-water line (MLW) or the land between the uplands or landward side of the submerged seaward lands (Oertel 2005). As shown in Figure 4, the tidelands can range in size and

constantly shift when the shoreline changes. Private ownership of the tidelands in the Commonwealth of Massachusetts extends to the MLW mark under Chapter 91, distributing ownership of the coastline between private coastal property owners and the Commonwealth (Massachusetts General Laws, c. 91).



Figure 4. The boundary of the public trust area known as the tidelands or the lands between mean high and mean low water (Department of Energy & Environmental Protection 2020).

The establishment of ownership of the coastline under Chapter 91 separated coastal geography into respective planning regimes; privately led planning above MLW, while the Commonwealth governed the tidelands below (Kittinger and Ayers 2010; Neal et al. 2018; Zakhour and Metzger 2018). Coastal ownership of the tidelands allows for the influence and development of the coastline by private property owners (Zakhour and Metzger 2018) (Zakhour and Metzger 2018). Development of the coastline will be determined by individual risk influenced by physical factors such as erosion rates, elevation, decisions of neighboring landowners, and costs (Beasley and Dundas 2021; Jin et al. 2015). Under the current system, where Chapter 91 establishes ownership of the tidelands to MLW, shorelines' ecological value and public value are considered separate from a private property owner's right to alter the shoreline (Kittinger and Ayers 2010). Legal precedent regarding coastal hardening favors coastal property owners'

interests. If personal property is considered at risk in a coastal area, shoreline hardening is deemed acceptable, which leads to increased hardening (Bilkovic et al. 2017).

Historically, affluent property owners and communities have hardened their shorelines, while “communities without the economic means to construct walls simply fell into the sea” (Pilkey and Wright 1988, 42). Private property owners have unequal influence regarding shoreline stabilization practices, which means that the actual costs and benefits associated with the various shoreline stabilization are likely underrepresented, and a systems-wide approach is not adopted (Gittman et al. 2021). Ownership of the tidelands has led to a lack of holistic planning the tidelands, and coastal property owners manage the approach taken when addressing shoreline change (Neal et al. 2018; Gittman et al. 2021). This model, where affluent coastal property owners determine decision-making in the tidelands, leads to a “tyranny of small decisions,” resulting in a less-than-optimal outcome for the ecosystem and society (Gittman et al. 2021, 2). As private property owners harden the shoreline along their properties, holding their property line in place, many overlook the underlying issue that development along shorelines is ill-suited to the dynamic nature of the coastline (Kittinger and Ayers 2010).

This thesis does not analyze economic inequality along the coastline; however, it is imperative to note that current stabilization practices in the tidelands cause disproportionate impacts on environmental justice (EJ) communities (or people of color and low-income communities (Domingue 2022; Masozera, Bailey, and Kerchner 2007; Ojanen et al. 2017; Tubridy, Lennon, and Scott 2022). It is essential to highlight that due to a system of discrimination and injustice, EJ communities are more likely to live in floodplains and have

limited resources to recover from the impacts of intensifying hurricanes, increasing flooding, and sea level rise (Masozera, Bailey, and Kerchner 2007). While this topic is not a focus of this thesis, the vulnerability of these communities to coastal hazards must be included in any future planning and policy decisions that take place along the coastline.

In the Commonwealth of Massachusetts, coastal property owners cannot alter the rate at which temperatures rise, a shore erodes, or the path of a storm; however, ownership of the coastline plays a critical role in managing it. This thesis explores the role that coastal property owners play in stabilizing the shoreline of the Commonwealth, weighing the impact of granting private ownership of the tidelands on which shoreline stabilization techniques are utilized. Including a brief analysis of the current regulatory landscape in the Commonwealth, which seeks to avoid and, wherever possible, mitigate change to the coastline. The final chapter of this thesis will explore policy recommendations to increase the use of nature-based solutions, avoid future hardening of the coastline, and address the perception of risk by coastal property owners. To explore these issues in more depth, this thesis will engage with the following research questions:

Research Questions:

- When stabilizing shorelines, what are the tradeoffs between traditional hardening techniques and nature-based solutions?
- What has led to 27% of the Massachusetts coastline being hardened using traditional hardening techniques such as breakwaters and seawalls?
- What policy changes are needed concerning a coastal property owner's ability to harden the shoreline in the Commonwealth of Massachusetts?
- What is the role of private property owners in current and future shoreline stabilization practices?
- What approaches could be taken to increase the use of nature-based practices in the Commonwealth of Massachusetts?

Chapter 2: Literature Review

This literature review will focus on shoreline stabilization practices to mitigate shoreline retreat. The techniques currently employed by property owners to defend coastlines vary in their construction practices, materials used, and ecological impact. A successful strategy will depend on many factors, including geographical location, scale, costs, community, and infrastructure (Miura et al. 2021). Three practices are commonly available to manage shoreline erosion: hard stabilization, soft stabilization, and retreat (Pilkey and Wright 1988). Hard stabilization practices utilize an approach that creates an engineered barrier between the shoreline and the sea to maintain the shoreline. Soft stabilization aims to restore the shoreline by employing ecologically based practices. Lastly, a retreat approach suggests that erosion is inevitable and irreversible and that the most effective solution is to relocate away from the shoreline. This literature review will explore the methods and effects of different shoreline stabilization strategies.

Hard Stabilization:

Historically, strategies to address erosion have focused on holding the existing shoreline in place and not allowing a coastline to retreat due to erosion and rising sea levels. To manage shoreline retreat due to erosion, storm risks, and SLR, a hard stabilization approach utilizes an engineering first model focused on constructing permanent hardened structures such as vertical seawalls, bulkheads, revetments, and breakwaters (Gittman et al. 2015). This approach is most commonly utilized in industrialized countries with large coastal populations vulnerable to coastal hazards such as storms, shore erosion, and tropical cyclones (Gittman et al. 2015).

There is a demand for the construction of hardened structures which have proven effective and, at times, necessary in areas where natural buffers have been irrevocably lost (Massachusetts Office of Coastal Zone Management 2011). Hardened structures vary in materials used, cost, size, effectiveness, and lifespan (Griggs 2005). The engineering of hardened structures can range from the use of concrete “simply dumped” at the base of an eroding slope in an attempt to reduce wave impact and slow erosion to a methodically engineered structure that can include a 50-year design life (Santosh Kumar, Sannasiraj, and Murali 2021; Griggs 2005). In the United States, 14% of the shoreline is hardened, and 64% of that hardening is located along the Atlantic and Pacific sheltered shorelines, which contain ecosystems such as estuaries and intertidal zones (Gittman et al. 2015). Hardened structures are often utilized along the coastline due to their small footprint and ability to mitigate harsh wave conditions with high surges (Hosseinzadeh et al. 2022).

Hardened coastal structures, also referred to as ‘armored structures,’ consist of two approaches; one that runs parallel to the ocean environment and the other that is perpendicular to the sea (Charlier, Chaineux, and Morcos 2005). Seawalls and revetments are parallel structures commonly constructed along the coastline, using concrete, stone, and steel to minimize the impacts of wave energy on the coastline (Gittman et al. 2015). Independent of material, parallel seawalls deflect wave energy, increasing wave and storm surge protection (Charlier, Chaineux, and Morcos 2005). Concrete is the second-most used material globally and is most often used during the construction of hardened structures because it is cost-effective, moldable, durable, and can reduce wave impacts, coastline erosion, and flooding (Hosseinzadeh et al. 2022). Seawalls most commonly utilize steel-reinforced concrete and are considerable in

length and height (Hosseinzadeh et al. 2022). In terms of mitigating waves, bulkheads are commonly used in situations where there are relatively low energy waves, seawalls are larger structures designed to withstand the direct attack of ocean waves, while revetments are intended to have a gentle slope designed to dissipate wave runup (Nordstrom 2014). The Boston Harbor region has roughly 111 concrete seawalls/bulkheads spanning 6,880 meters in length (Fontenault, Vinhaterio, and Knee 2013).



Figure 5. Seawall along Lynn Shore Drive, in Lynn, MA reducing the impact of high energy waves during a winter storm in 2021 (Garfinkel 2021).

Located offshore, breakwaters can also be utilized to reduce or eliminate wave energy and contribute to deposition on beaches landward of them (Nordstrom 2014). Suitable in micro-tidal situations, the structures can be designed to act as an offshore reef, providing shelter for new habitats to form landward of them, such as *Spartina* marsh (Nordstrom 2014).

Significant research has been conducted to improve the performance of hardened structures, such as innovative seawall designs, ecological considerations, and durability performance testing (Hosseinzadeh et al. 2022). An example is a curved seawall design which reduces a wave's ability to overtop a structure and redirects wave energy in a seaward direction; this innovation in design is effective and performs well compared to vertical walls (Hosseinzadeh et al. 2022). Some hardened approaches are now adopting an "ecoengineering" approach that seeks to maximize biodiversity through novel artificial structures such as rock pools or pits and planted vegetation that can be incorporated into new seawalls during construction to provide an alternate habitat for marine life organisms (Hosseinzadeh et al. 2022).

Factors such as storm frequency, population density, gross domestic product (GDP), and vessel traffic influence the likelihood of shoreline hardening (Gittman et al. 2015). In the paper *Engineering Away Our Natural Defenses: An Analysis of Shoreline Hardening in the US*, Gittman et al. (2015) noted that coastlines that experienced seventeen or more harsh storm events between 1970 and 2010 had a higher percentage of hardened shorelines. Frequent storm events, such as tropical cyclones in Massachusetts, threaten local communities and infrastructure, especially in densely populated cities seeking guaranteed protection during significant storm events (Yoo, Sinha, and Mendelsohn 2022). In densely populated cities, the damage per unit of length of the coastline is increased due to a significant amount of buildings lower than two meters in elevation, leading to a considerable number of vulnerable low-lying buildings where the benefit of a seawall would exceed the cost (Yoo, Sinha, and Mendelsohn 2022). When protection is the primary goal, hard stabilization offers a tangible solution that has

already been implemented and tested, offering a constructive way to reduce flooding damage in low-lying dense coastal cities (Mendelsohn and Zheng 2020).

A recent study *Engineering Away Our Natural Defenses: An Analysis of Shoreline Hardening in the US*, found that housing density and GDP are significant predictors of hardening, and a considerable amount of coastal metropolitan areas are heavily hardened regardless of other physical shoreline characteristics or processes (Gittman et al. 2015). This research is consistent with Boston Harbor's highly developed coastline, where 58% of the region's shoreline is hardened (Fontenault, Vinhaterio, and Knee 2013). One attribute of a heavily populated coastline is the impact of marine vessel traffic on the shoreline. Although commercial and recreational boating contributes to a robust coastal economy, the activity often results in intensive and frequent vessel traffic (Bilkovic et al. 2019). An example is the Thompson and Spectacle Islands in Boston Harbor, which experience higher wave energy levels due to regular traffic (FitzGerald, Hughes, and Rosen 2011). Hard stabilization structures have effectively reduced erosion from boat wakes and therefore have been heavily utilized in metropolitan areas (Bilkovic et al. 2017).

One factor influencing the construction of hardened shorelines is the increase in perceived safety from storms for some homeowners. One study, *Shoreline Change, Seawalls, and Coastal Property Values*, conducted on the South Shore of Massachusetts (Marshfield, Duxbury, and Plymouth), found that coastal properties with a seawall in immediate proximity to the ocean resulted in an average marginal increase in property value of 10% (\$48,000) (Jin et al. 2015). Once shoreline hardening has occurred, the development behind the structure tends to increase behind it, heightening motivation for the continuation of this type of protection (Hino,

Field, and Mach 2017). Additionally, there is a strong correlation between hazard protection of coastal properties encouraging more development in hazardous locations (Armstrong et al. 2016; Woodruff, BenDor, and Strong 2018). A recent study (2017) found that coastal property owners “perceive bulkheads to be the most durable and effective at preventing erosion, but also the most costly; compared to residents with revetments and natural shorelines, property owners with bulkheads reported double the price to repair hurricane damage to their property and four times the cost for annual shoreline maintenance” (Smith et al. 2017, 350).

Hard-engineered structures allow property owners to protect their property and slow the erosion rate to their coastline; however, hardened shorelines also present a complex landscape with discernible tradeoffs. Concerns regarding seawalls include deterioration of the structure, steel in the seawalls corroding over time, changes to beach sediment budget, and ecological degradation (Hosseinzadeh et al. 2022; Nordstrom 2014). In their paper *The Impacts of Coastal Armoring*, Gary Griggs notes, “On high energy and/or eroding coastline, any protective structure built to withstand direct wave attack will eventually fail. Even a well-designed structure is likely to fail once its design life has been exceeded, especially if it has not been properly maintained” (Griggs 2005, 15). Even when hardened structures have been constructed with a 20 to 50-year design life, some have been destroyed within a year, and others have lasted for over 50 years; however, most will lose functionality and need repair or retrofit within their design life (Griggs 2005; Santosh Kumar, Sannasiraj, and Murali 2021). Hardened structures deterioration is often accelerated due to climate change’s impact on the marine environment (Santosh Kumar, Sannasiraj, and Murali 2021). As an example, climate change impacts the rate of carbon dioxide the ocean absorbs, causing seawater to be more

acidic, impacting the chemical composition of concrete, and increasing corrosion of rebar, which aids in stabilizing the structures (Santosh Kumar, Sannasiraj, and Murali 2021). The degree of success of hardened structures is highly variable, and effectiveness depends on the quality of the structure's design, coastal climate, and storm history, among other factors (Pilkey and Wright 1988).

A primary drawback of shoreline hardening is the adverse impact on beaches and sediment budgets throughout time (Nordstrom 2014). In their paper *Living with shore protection structures: A review* Karl Nordstrom (2014) discusses the impacts of structures such as seawalls on the sediment budget, including loss of physical beach due to wall placement, narrowing of the beach due to passive erosion, active erosion due to wave interaction with the structure, and reduction in sediment transport to downdrift beaches. Hardened structures limit the two-way sand exchange when a structure impedes sediment's landward progression; this affects dune formation and sediment being supplied from dunes to eroding portions of the beach (Gittman et al. 2015; Pilkey and Wright 1988; Perkins et al. 2015). This causes impoundment loss in locations where sand from eroding dunes or cliffs previously represented a sizable portion of sediment supply to adjacent beaches; however, the sand is now trapped by hard structures (Brucal and Lynham 2021). Additionally, hardened stabilization structures reflect wave energy, magnifying the power of retreating waves that pull sand away from the structure, creating a steeper underwater slope in front of hard structures (Brucal and Lynham 2021). This sediment movement results in sediment scour, similar to erosion, where sediment moves out to sea, and the loss of sediment threatens the structure, potentially leading to structure failure (Gittman et al. 2015; Hosseinzadeh et al. 2022; Sumer and Fredsoe 2002; Xie et

al. 2019). Hardened structures may be responsible for more than 80% of the loss of soft-sedimentary shorelines (Chapman and Underwood 2011).

A growing body of scientific evidence indicates that hardened shorelines also present ecological concerns. Hardened shorelines, specifically parallel structures such as seawalls, act as an ecological barrier that fragments coastal lands from wetland functions, reduces filtration and nutrient uptake, increases wetland loss and changes coastal ecosystems (Bilkovic et al. 2017; Perkins et al. 2015). Additionally, due to hardened structures' impact on the sediment budget, species that utilize the beach will be negatively impacted (Nordstrom 2014). Parallel structures such as seawalls affect the intertidal zone, causing it to become steeper and shorten over time, providing a less physically complex habitat than natural shorelines (Jaramillo et al. 2021). The habitat changes significantly impact the intertidal zone's biodiversity, restricting and eliminating species in part due to a lack of available habitat (Jaramillo et al. 2021). When coastal structures are located in the intertidal zone, they impact natural ecosystem services and result in the loss of critical coastal ecosystem services such as "provision of nursery habitat for commercially and recreationally valuable fish and crustaceans, filtration of nutrients and pollutants from terrestrial runoff, carbon burial, and erosion protection" (Gittman et al. 2015, 306). Changes in species richness will occur at every trophic level, from diversity and abundance of macro-invertebrates in lost wrack accumulation, spawning habitat for species such as horseshoe crabs, and reduction in the abundance of foraging shorebirds (Nordstrom 2014). The impacts of hardened structures increase when tidal ranges are more extreme or a structure has become submerged due to sea-level rise, causing shore areas to become fragmented from the ocean (Perkins et al. 2015).

Hard stabilization practices continue to be widely accepted and utilized; however, their protection value is overinflated and causes considerable damage to the local environment. In a recent study (2021), *Resistance, resilience, and recovery of salt marshes in the Florida Panhandle following Hurricane Michael*, Castagno et al. compare the damages due to storm flooding along both hardened (artificial) and natural (nature-based features such as salt marshes). The study found that:

Very few marshes were damaged or failed during a direct hit from one of the strongest hurricanes to impact the continental United States, and marsh failure rate was generally much lower than that seen for other artificial defenses, even in lower-intensity storms. A portion of damaged marshes also began to recover within six months with few or no interventions, which artificial defenses cannot. Managed marshes on public lands are more likely to be both resistant and resilient to storm damage (Castagno et al. 2021, 6).

Orrin H. Pilkey and J. Andrew G. Cooper note that the greatest threat to the integrity of coastlines is the coastal-engineering profession and the impacts of shoreline hardening (Pilkey and Cooper 2014). Hard stabilization practices foster a false sense of security for coastal property owners, the approach does not fully mitigate the threats of coastal hazards, and strategies present expensive short-term solutions, that often fragment local ecosystems (Massachusetts Office of Coastal Zone Management 2011; Smith et al. 2017). The impacts and cost of shoreline hardening often do not outweigh the benefits, especially when effective alternative strategies are readily available. Academic literature supports a strategy shift toward an ecology first model that explores utilizing nature-based solutions rather than an engineered first model that relies on future shoreline hardening (Bilkovic et al. 2016; Davenport et al. 2018; Gittman et al. 2016; Smith et al. 2018).

Soft Stabilization:

Soft shoreline stabilization practices include a wide range of techniques, with varying environmental considerations, technical constraints, and performance expectations depending on the characteristics of the shoreline (Gianou 2014). Soft stabilization practices seek to prevent erosion and, wherever possible, maintain a natural shore and habitat, similar to habitat restoration and rehabilitation (Chapman and Underwood 2011; Pontee et al. 2016). Soft stabilization practices are intended to stabilize the shoreline and include co-benefits such as improvements to species habitat, water quality, and ecological conditions (Gianou 2014; Gittman et al. 2015).

Soft shoreline stabilization was first developed as dredge-and-fill projects to combat shoreline erosion, beginning with the first beach nourishment in the United States at Coney Island, New York, in 1923 (Hanson et al. 2002; Peterson and Bishop 2005). During this time, planners sought to develop new approaches to protect the coasts and to rebuild beaches through soft stabilization in the form of beach nourishment (Charlier, Chaineux, and Morcos 2005). Beach nourishment is the process of obtaining sediments from a dredge site or terrestrial source, which are then added to the beach to elevate it and extend it seaward (Peterson and Bishop 2005). This practice has been used to mitigate coastal storm damage or chronic erosion and improve beaches for recreational purposes (Armstrong et al. 2016; Hanson et al. 2002; Peterson and Bishop 2005). Charles H. Peterson and Melanie J. Bishop discuss in their paper *Assessing the Environmental Impacts of Beach Nourishment* that “Unlike seawalls and groins that act only to harden the shoreline or redistribute sediment, nourishment temporarily adds sediment to the beach system” (Peterson and Bishop 2005, 887).

Artificial beach nourishment creates a sacrificial buffer for coastal property, which in turn, increases protection to properties landward of the beach from storm damage (Coburn 2012). Additionally, this approach increases recreational space along the shore, and replicating natural coastal processes (Coburn 2012). Artificial beach nourishment has been “a leading form of coastal protection in the United States for four decades” (Armstrong et al. 2016, 626). Figure 6 below is a heat map showing the location and intensity of beach nourishment in the United States (Coburn 2012).

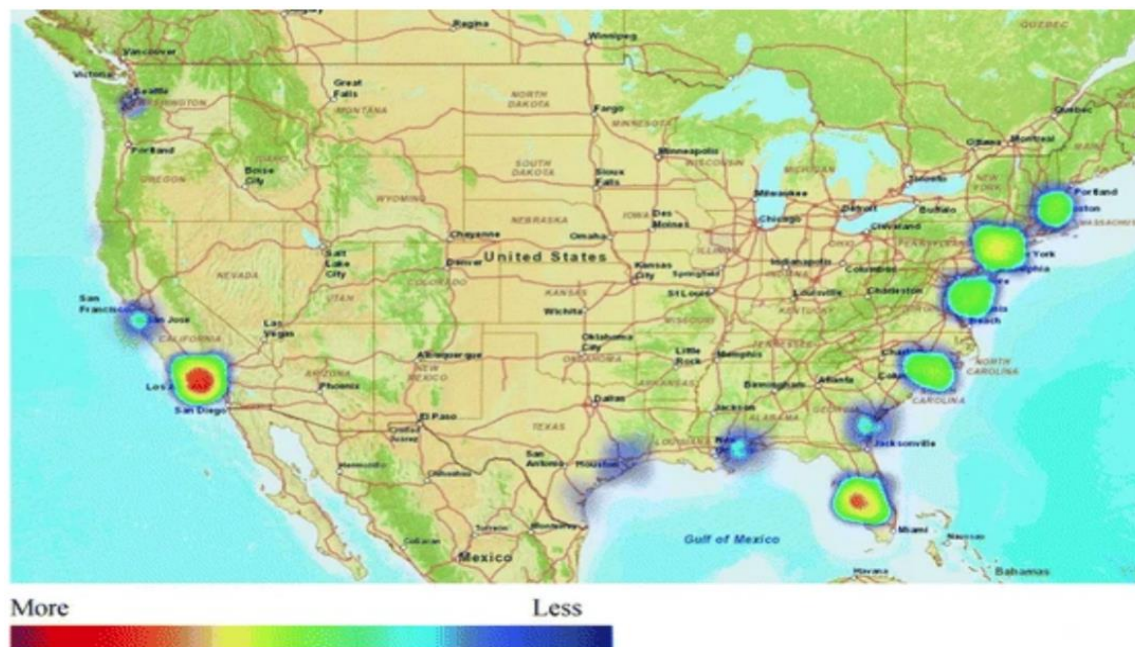


Figure 6. Location and Intensity of Beach Nourishment in the United States (Coburn 2012).

Although beach nourishment has assisted in combating shoreline retreat, nourishment projects are not often ecologically driven (Peterson and Bishop 2005). During the construction phase of beach nourishment, multiple activities are harmful to local ecosystems, including the quantity of sand used, the nourishment technique, and the strategy (Speybroeck et al. 2006). Like hard stabilization’s impact on the intertidal zone, beach nourishment heavily impacts the

sand beach habitat, which supports the seasonal nesting of sea turtles, shorebirds, and crabs (Dean 2005; Peterson and Bishop 2005). Roger H. Charlier, Marie Claire P. Chaîneux, and Selim Morcos note in their paper *Panorama of the History of Coastal Protection* that “Artificial nourishment has been carried out in many sites; however, it too has come under fire to the extent of being likened—perhaps unfairly—to building sand castles” (Charlier, Chaîneux, and Morcos 2005, 99). This is because beach nourishment typically lasts between three and five years before a beach reverts to its pre-nourishment dimensions and needs renourishment, and creates a false sense of security for homeowners on the coast (Coburn 2012). In one study, *Indications of a Positive Feedback Between Coastal Development and Beach Nourishment*, the authors found that “houses in nourishing zones are significantly larger and more numerous than in non-nourishing zones, and that the largest houses in nourishing zones are among the most recently built” (Armstrong et al. 2016. 262).

While beach nourishment is a soft stabilization approach to erosion mitigation, it should be considered a bridge from hard stabilization to an ecology-first model or an evolutionary process that has given way to the field of nature-based solutions (NBS). NBS has become a catch-all for soft stabilization approaches that prioritize working with natural environmental landscapes to improve coastal protection (Pontee et al. 2016). These approaches are similar to hard stabilization strategies designed to protect property and prevent erosion; however, NBS also seek to appear natural and be consistent with the character of coastal communities and uses of the shore (Bilkovic et al. 2016; Woods Hole Group 2017). NBS aim to enhance ecosystem services such as nutrient recycling, erosion control, and carbon sequestration (Pontee et al. 2016). A recent study *Living Shorelines Can Enhance the Nursery Role of*

Threatened Estuarine Habitats, found that, unlike shoreline hardening, NBS can improve a marsh's ecosystem services, such as nursery habitat, while protecting the shoreline against wave action (Gittman et al. 2015). Although the costs of NBS can vary based on site characteristics, once established, NBS are typically seen as low-cost options that are cheaper and easier to maintain than hard engineering structures (Pontee et al. 2016). Due to the positive impacts of NBS, these soft stabilization approaches have gained popularity when aiming to restore coastlines and aid in a shoreline's ability to be more resilient in response to climate change (Bilkovic et al. 2016).

NBS includes various terms such as bioengineering, living shorelines, engineering with nature, ecological engineering, and green infrastructure (Gianou 2014; Pontee et al. 2016; Smith et al. 2018). However, these terms can cause confusion due to a “lack of specific details about the physical elements of the solution” (Pontee et al. 2016, 12). In the paper *Nature-Based Solutions: Lessons From Around the World*, the authors note that a challenge in soft stabilization approaches is confusion about what constitutes NBS (Pontee et al. 2016). “Ecologists might consider NBS to include only solutions with a living element (e.g., marshes, mangroves, reefs). Engineers, on the other hand, commonly use the term NBS to describe solutions that use or mimic natural processes (e.g., beach nourishment projects that rely on coastal processes to redistribute the sediment)” (Pontee et al. 2016). NBS can include entirely natural solutions such as vegetated marshes, hybrid solutions that combine structural engineering with natural features such as a marsh–levee system, or environment-friendly structural engineering such as vegetated engineering (Pontee et al. 2016). NBS seek to combine some of the best

characteristics of natural and engineered shorelines to improve coastal resilience (Smith et al. 2018).

An example of the ambiguous of terms under the NBS umbrella is “living shorelines,” leading to the conclusion that all components of the strategy would need to be organic; however, the approach seeks to have the dominant elements be organic or living materials (Bilkovic et al. 2016). Living shorelines utilize engineered structures; however, they are only used to support vegetated habitats and are designed to avoid overwhelming the living habitat features they support (Bilkovic et al. 2016). Soft non-structural NBS elements are most successful in low-energy environments, while higher-energy environments may require a hybrid-engineered approach (Bilkovic et al. 2016).

The US Army Corps of Engineers (USACE) recently created a framework and metrics to evaluate NBS alternatives alongside other shoreline stabilization strategies for the Atlantic coast (Bridges et al. 2015). In the report titled *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*, USACE created 21 agreed-upon relevant ecosystem goods and services that can be gained from different strategies, including services typically associated with traditional hardened stabilization strategies (Bridges et al. 2015). These services include evaluating a strategy’s ability to provide erosion protection and control, property value protection, storm surge reduction, and wave attacks (Bridges et al. 2015). In this report, living shorelines were identified as an effective mitigation strategy to provide the services commonly associated with hard stabilization. When ranking a strategies ability to provide all twenty-one goods and services, living shorelines scored a sixteen while seawalls scored a nine on the matrix (Bridges et al. 2015). Softer solutions such as living shorelines can measure up against

traditional strategies while providing additional goods and services such as biological diversity, carbon sequestration, habitat for fish and wildlife provisioning, and opportunities for tourism (Bridges et al. 2015).

A challenge when implementing NBS is that the guidelines for NBS are less established than for hardened stabilization approaches (Pontee et al. 2016). A lack of available research and the body of evidence to support the use of NBS in various environments has limited its widespread use. The protection provided by NBS is less understood than conventional hardened stabilization structures (Pontee et al. 2016). Some of the seawalls in Boston Harbor date back to 1784, evolving with time and adapting as more modern approaches became available (Rosen and Vine 1995). As technology and scientific understanding of coastlines have evolved, soft stabilization approaches such as NBS have met resistance due to a relative lack of experience regarding performance (Pontee et al. 2016).

A strategy's ability to perform, is critical when managing individual risk aversion, since "public perception of risk is driving policy as much as technological and scientific risk assessments" (Peacock, Brody, and Highfield 2005). As the literature continues to increase, NBS will need to address site-specific questions about their effectiveness in different situations. To turn the tide on the applicability of NBS, stakeholders will need data to support their use, including how a material performs in particular environments, such as the Commonwealth's unique coastline and climate (Davenport, Kirk, and Bowden 2022). To increase the prevalence of NBS in Massachusetts, targeted academic literature should address whether NBS perform better than traditional (hardened) materials regarding shoreline stabilization (Davenport, Kirk, and Bowden 2022). In a recent paper (2022), *Regulatory Challenges and Opportunities for Living*

Shorelines in New England, authors discuss the challenges of implementing living shorelines in states such as the Commonwealth, remarking that:

Living shorelines are increasing in frequency in some regions of the United States, while adoption of living shorelines in New England lags in comparison. Environmental conditions in New England, including shorter vegetation growing seasons, ice and associated scour, and large (2 meter) tide ranges pose challenges for appropriate project design, though plenty of viable options are available (Davenport, Kirk, and Bowden 2022, 11).

Institutions such as the Stone Living Lab will be critical in producing academic literature that assesses the effectiveness of NBS. The Stone Living lab is a partnership between the City of Boston, UMass Boston School for the Environment, Boston Harbor Now, the National Parks of Boston, the Massachusetts Department of Conservation and Recreation, and the James M. and Cathleen D. Stone Foundation (Stone Living Lab 2022). The lab seeks to test and scale up NBS for climate adaptation, coastal resilience, and ecological restoration in the high-energy environment of the Boston Harbor Islands National and State Park (Stone Living Lab 2022). As the academic literature continues to develop to support the use of NBS, the threats due to climate change are likely to require additional solutions to manage the changing coastline beyond even hard and soft solutions. A technique which will move people and assets out of harm's way as discussed below (Siders 2019).

Managed Retreat:

A strategy to mitigate erosion which is gaining recognition is managed retreat: the planned, purposeful relocation of homes and infrastructure under threat due to coastal flooding and erosion (Alexander, Ryan, and Measham 2012; Hino, Field, and Mach 2017; Siders 2019). In some coastal communities, retreat will be unavoidable and one of the few

stabilization options available for coastal property owners facing long-term risks from sea-level rise. The magnitude of developed coastal lands alone will drive the need for managed retreat. There is \$1.4 trillion worth of real estate already located within 700 feet of the coastline in the United States (Siders 2019). A benefit of retreat, as opposed to soft and hard stabilization approaches, is that once implemented, there are minimal recurring financial costs in the form of maintenance costs (Hino, Field, and Mach 2017). In many instances, the cost of stabilization can exceed the value of the property and the cost of moving a structure (Neal, Bush, and Pilkey 2017). A retreat can come in the form of active relocation by moving a building back or raising it, or passive relocation by rebuilding a destroyed structure in another area away from the hazard area (Neal, Bush, and Pilkey 2017).

Managed retreat permanently reduces risks compared to alternative approaches (Hino, Field, and Mach 2017). A historical example of an organized retreat is Long Point in Provincetown, MA. Long Point was located on the tip of Cape Cod, close to rich fishing grounds, with a schoolhouse and salt manufacturing infrastructure (Jennings 1890). When life became unlivable out on “the point” due to erosion and drought, the population decided to float their houses and buildings, such as the schoolhouse, on boats across the bay to the West End of Provincetown (Binder and Speicher 2003; Jennings 1890; Paine-Smith 1922). This approach ensured the longevity of critical infrastructure in town, and as a result of the retreat, some structures can still be found in Provincetown today, prominently displaying a floating house on a blue plaque. Figure 7 shows a map of the settlement of Long Point when the homes were floated across the harbor (Paine-Smith 1922).

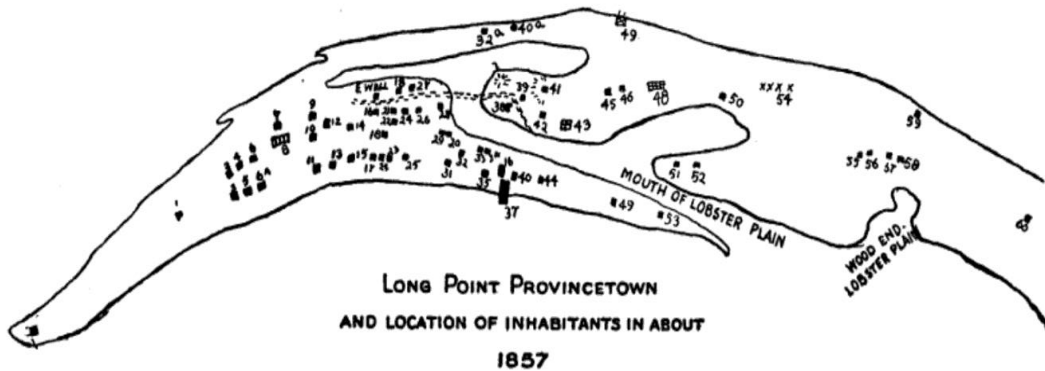


Figure 7. Settlement of Long Point in Provincetown, MA where residents were forced to participate in an organized retreat (Paine-Smith 1922).

Coastal property owners in Provincetown will again be in a position to consider retreat as the Town becomes increasingly vulnerable to storm surge and erosion. Today, residents can again see retreat being used as an approach at Herring Cove Beach Parking Lot in Provincetown. Storms and erosion have washed away most of the north lot and revetment, and the National Park Service has selected the strategy managed retreat to relocate the parking lot to re-establish a natural shoreline (Carlstrom 2018).

Although achieving large-scale retreat could significantly benefit social, economic, and ecological systems, it would require coastal property owners to reconceptualize their relationship with risk and what it means to own property (Siders 2019). Managed retreat as a strategy becomes challenging due to coastal property owner's cultural attachment to place, constitutionally protected ownership rights, and irrational barriers such as underestimating risk and overestimating protective measures such as seawalls (Hino, Field, and Mach 2017; Siders 2019). Hino, Field, and Mach noted in their study, *Managed Retreat as a Response to Natural Hazard Risk*, that there are two parties with motivations to initiate a managed retreat: a coastal property owner and an implementing party which is most often a government entity (Hino,

Field, and Mach 2017). Their study found that the attitudes of both parties depend on their values and perceived risk levels (Hino, Field, and Mach 2017). Figure 8 represents the perspectives of the coastal property owner (residents) and implementing party (broader society) (Hino, Field, and Mach 2017).

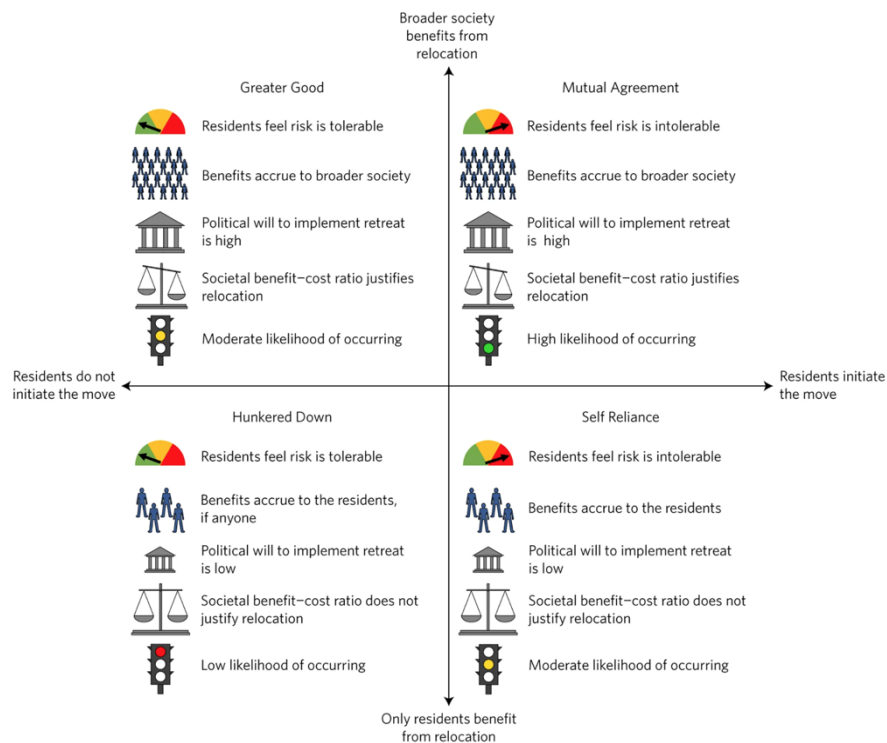


Figure 8. Coastal Property Owner and Implementing Party's Perspectives.

Figure 8 also demonstrates the complexity involved in the strategy of retreat, including risk aversion, benefits to residents, political will, societal benefits, and the likelihood of occurrence (Hino, Field, and Mach 2017). The benefits include reduced expenditure on disaster relief, improved environmental protection, or reduced exposure to natural hazards (Hino, Field, and Mach 2017).

In their paper *Managed Retreat in the United States*, A.R. Siders notes that “difficult decisions about who pays and who receives support will inspire difficult conversations about

past injustices and current inequalities (Siders 2019). “Politicians and community leaders must put long-term communal good above short-term economic or political gain. Nationally, it might require Americans to reconceptualize our relationship with risk and what it means to own property” (Siders 2019, 216). Historically, the US Federal Emergency Management Agency (FEMA) has funded managed retreat through the National Flood Insurance Program (NFIP), “which allowed owners of threatened buildings to use up to 40% of the federally insured value of their homes for building relocation purposes” (M. Schwartz 2006, 604). However, NFIP has been bankrupt for years; A.R. Siders explains that “not enough at-risk property owners participate in the program to spread the risk, and those who do participate have artificially discounted premiums, so they do not pay the full cost of living in risk-prone areas” (Siders 2019, 219). Recent federal grant programs such as the FEMA BRIC (Building Resilient Infrastructure and Communities) have substantially increased funding for relocation and/or include relocation of infrastructure outside of hazard areas as a benefit in the benefit-cost analysis required by the program (FEMA 2021). Financial incentives such as grant funding will be a necessary component of implementing this strategy, however, even if well-funded there will still be considerable opposition to this practice compared to hard stabilization practice (Siders 2019).

Conclusion:

This literature review highlights that all three techniques currently employed as coastal erosion mitigation strategies present varying benefits and challenges. Additionally, it demonstrates a juxtaposition between data-driven evidence and one’s perceived ability to reduce risk. That the landscape surrounding shoreline stabilization practices, involves a complex

web of costs, benefits, and stakeholders. The following chapter examines the role of one stakeholder group that maintains unequal influence regarding which stabilization practice is utilized – the private coastal property owner.

Chapter 3: Ownership of the Coastline – Chapter 91

Site-specific decision-making regarding shoreline stabilization has been established in the United States based on property ownership. In Massachusetts, authority over the coastline is determined by a generally agreed-upon set of rules that require, forbid, or permit specific actions in the tidelands (Schlager and Ostrom 1992). These rules determine property rights in the intertidal zone, and establish jurisdictional boundaries (Davenport, Kirk, and Bowden 2022; Schlager and Ostrom 1992).

The Fragmentation of the Tidelands

Ownership is a critical component of the management of the “coastal zone” or “buffer zone,” which in Massachusetts extends 100 feet landward of wetlands and includes all islands, transitional and intertidal areas, coastal wetlands, and beaches (Massachusetts Office of Coastal Zone Management 2011). Ownership of the coastline in the Commonwealth dates back to the Massachusetts Public Waterfront Act (Chapter 91) of the Massachusetts General Laws. Chapter 91 originated from the Massachusetts Bay Colony’s Colonial Ordinances of 1641-1647 and was formally established in 1866 (Commonwealth of Massachusetts 2022c). Administered by the Massachusetts Department of Environmental Protection (MassDEP), it is one of the Commonwealth's primary laws for managing the tidelands. As the shoreline has become more developed, Massachusetts’ tidelands management program has become increasingly complex (Portman 2006). Private ownership of the tidelands in the Commonwealth of Massachusetts extends to the mean low water mark (MLW), in contrast to other coastal states where ownership only extends to the mean high water mark (MHW) (Jin et al. 2015).

Chapter 91 is a Public Trust Doctrine that establishes to what extent private property owners can claim ownership of the tidelands (Commonwealth of Massachusetts 2022c; Takacs 2008). Rights of the tidelands go back 1,500 years to the Roman empire when Roman Emperor Justinian codified that “by the law of nature these things are common to all mankind, the air, running water, the sea and consequently the shores of the sea” (Takacs 2008, 713). Public Trust Doctrines are born from the idea that specific resources are “common” or shared property of the public while the state holds the legal title of the land (Takacs 2008). Under Chapter 91, the Commonwealth is the trustee of the tidelands, and its residents are the beneficiaries. This distinction is intended to manage the competing interests in the tidelands. When the statute was first established in 1866, policymakers were interested in granting private ownership of the tidelands to encourage waterfront development (Portman 2006). During that time, the colonial government was cash-poor, and promoting commercial ties between land and sea was economically advantageous (Department of Environmental Protection 2003; Moran, Miller, and Shelley 2019).

The statute established ownership rights in the coastal zone extending property rights of upland property owners to adjacent tidal flats, including a compromise providing property ownership to MLW, with the Commonwealth retaining the tidelands below the MLW (Department of Environmental Protection 2003; Goodwin 2000). Tidelands which are privately owned are subject to public easement rights that ensure the public’s rights to fish, fowl, and navigate are not unreasonably restricted, while tidelands owned by the Commonwealth are held in a trust for public use (Massachusetts General Laws, c. 91) (Figure 9). While ownership of the tidelands varies by state, the Commonwealth is one of the few states in the country that

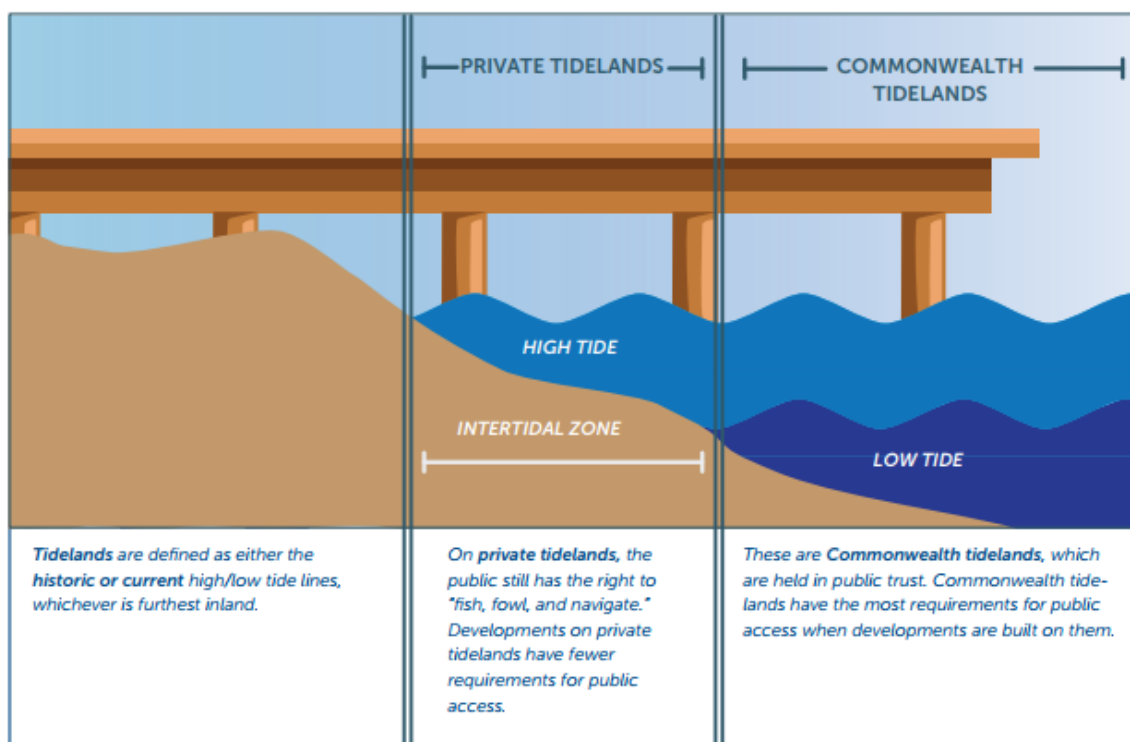


Figure 9. A visual description of the tidelands showing the difference between private and Commonwealth-managed tidelands (Conservation Law Foundation 2018).

grants ownership to MLW, and the Commonwealth was able to quickly discover the ramifications of granting ownership of the intertidal zone.

After the establishment of the Massachusetts Bay Colony in 1630, private property owners began to add artificial fill to their tidal flats and marshes, expanding the boundaries of their properties (Weiskel, Barlow, and Smieszek 2005). An example of filling former tidal flats is the Massachusetts lower Charles River watershed where the City of Boston now lies. The land is built on estuarine mud deposits, salt-marsh peat, and underlying glacial-marine clays, which are now entirely covered by artificial fill (Weiskel, Barlow, and Smieszek 2005) (Figure 10).

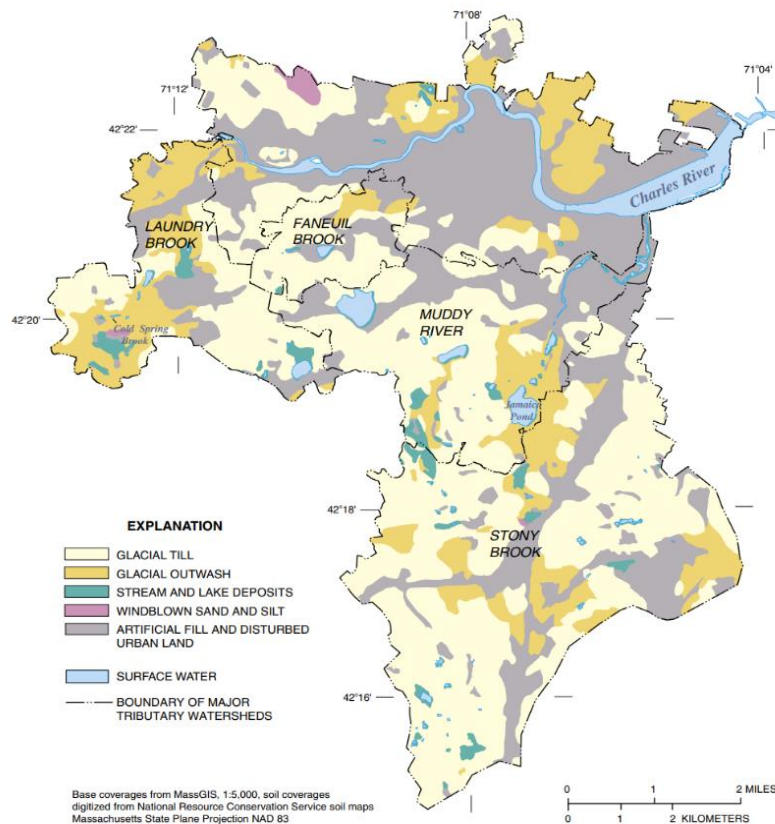


Figure 10. The area shaded in gray shows the artificial fill in the lower Charles River Watershed.

While Chapter 91 was initially created to promote coastal development, however, this led to private property owners permanently modifying the tidelands, doing irreputable damage to ecosystems, and impacting public access to the tidelands (Moran, Miller, and Shelley 2019).

Until the 1970s, when development along the coast began to transition from a working waterfront, and “maritime commerce uses and facilities were no longer the dominant type of development,” the relatively unchanged statute was challenged (Moran, Miller, and Shelley 2019, 7; Griggs 2005). Chapter 91 evolved for the first time when the Massachusetts Supreme Judicial Court issued its decision in *Boston Waterfront Development Corporation v. the Commonwealth*, 378 Mass. 629 (1979). The Court held that formerly submerged land that had

been filled and built upon nevertheless required considerations pursuant to a public trust (Dion Goodwin 2016). As a result of the Court's decision, the Massachusetts Legislature amended Chapter 91 to include language to differentiate between water-dependent and nonwater-dependent uses of the tidelands (Moran, Miller, and Shelley 2019). "Under the revised Act, water-dependent uses and structures on tidelands are presumed to serve a proper public purpose, whereas nonwater-dependent uses and structures, such as the proliferating residential and commercial office and hotel uses, are prohibited unless they are able to show that those developments promote and support public purposes sufficient for approval" (Moran, Miller, and Shelley 2019, 7-8). Examples of a nonwater-dependent project supporting a public purpose is a mitigation action to provide a public benefit, such as ferry docks, restrooms, and public parks (Moran, Miller, and Shelley 2019, 8). MassDEP notes that during this time, "the jurisdiction under Chapter 91 'came ashore' and filled tidelands have since been recognized as being under the same jurisdiction as those areas presently subject to the ebb and flow of the tide" (Department of Environmental Protection 2003, 4).

This change to the statute also highlighted an increased need to understand where the MHW shoreline currently lies and a need for the historic mean high water (HMHW) shoreline. Chapter 91 manages any project located in, on, over, or under tidal waters seaward of the present MHW shoreline, which includes any formerly submerged lands and tidal flats which are no longer subject to tidal action due to the presence of fill or beyond the HMHW shoreline (Department of Environmental Protection 2003). Chapter 91's jurisdiction relies heavily on the location of both MHW and HMHW. Chapter 91 provides clear procedures for a private landowner who wants to alter the shoreline, requiring a wetlands delineation to determine

MHW and heavily regulating projects below that line. However, for tidelands that were formally filled, the HMHW shoreline is used. The Commonwealth notes that “determining the Historic High-Water line for a specific site could be considered more of an art than a science” (Commonwealth of Massachusetts 2022b, par. 9) MassDEP depends on historical and hydrographic evidence to decide where HMHW lies (Commonwealth of Massachusetts 2022a). CZM and MassDEP completed a project to map the historic HWM in the Commonwealth in 2006 since the tideland’s jurisdiction data is updated on an ‘as needed’ basis. (BSC Group 2006; MassGIS 2011). The Commonwealth has invested significant resources into understanding the HMHW, and the program has sought to protect ecologically sensitive areas from “unnecessary encroachment by fill and structures” (Commonwealth of Massachusetts 2022a, par. 5).

An ever-shifting boundary between private and publicly owned tidelands means an ever-changing MHW, which presents a challenge in understanding the actual, current geographical jurisdictional limits of Chapter 91. In the Commonwealth, many areas, such as Nauset Beach in Orleans on Cape Cod, experience short-term erosion rate (30-year period from 1970-2009) of a loss of 5.7 feet per year (Coastal Erosion Commission 2015). As a result, MassDEP must evaluate every project that takes place along the coastline, and the shifting jurisdictional boundary which can include a loss of private and/or public tidelands which have eroded into the sea.

The Impacts of Private Ownership

While today Chapter 91 manages the coastline and plays a role in avoiding adverse impacts due to economic pressure, however, during its first hundred years, Chapter 91

regulations focused primarily on how altering the Commonwealth's shoreline impacted navigation and allowed for the use of shoreline stabilization structures to buffer the impacts of shoreline erosion (Portman 2006). During that time, property owners sought to protect their investments by stabilizing the coastline and reducing the effects of coastal erosion. The role of Chapter 91 in the landscape of shoreline hardening has been to preserve the value of a private property and public waterfront access (Charlier, Chaineux, and Morcos 2005). Legal precedent regarding shoreline stabilization lies in the custody of personal property owner's rights; if private property is considered at risk in a coastal area, shoreline hardening is deemed acceptable (Bilkovic et al. 2017). The statute was written through the lens of economic prosperity and society focusing on ownership of real property.

In large part because of the strength of Chapter 91 and its emphasis on private ownership rights, private stakeholders in the tidelands have an unequal influence on the composition of the coastline in Massachusetts. In the Commonwealth, 70% of coastal property is privately owned, and the Commonwealth's role in managing the coastline structure has been limited since the state's inception (Charlier, Chaineux, and Morcos 2005; Massachusetts Office of Coastal Zone Management 2011). This presents a significant challenge when managing the Commonwealth's coastlines and reducing vulnerability, since "the notion that all the stakeholders in a management issue can sit down and come to a compromise solution upon which everyone agrees, or that all of the stakeholders have an equal influence on making the rules" (Neal, Bush, and Pilkey 2017, 25).

Under Chapter 91, the unequal influence of the tidelands forms a private property regime where coastal property owners are guaranteed a right to develop the coastline (Hanna

and Munasinghe 1995). “Property rights regimes consist of systems of rules that govern access to and control over natural resources. These rules specify permissible and forbidden actions, responsibilities, and obligations among people and concerning natural resources. Property rights regimes are an essential part of natural resource governance as they affect how the costs and benefits of natural resources are distributed” (Ojanen et al. 2017, 2). Private property owners have the right to use the resource within the established rules; however, owners are likely driven by individual benefits and costs, ignoring their impact on others (Kittinger and Ayers 2010). The statute perpetuates a framework that allows individuals to reduce personal risk, regardless of the environmental consequences. One of the most common results of prioritizing self-interests is shoreline hardening, which impacts larger systems such as sediment transport and damages the ecosystem services provided by the intertidal zone but preserves personal property (Tavares, Fletcher, and Anderson 2020).

While likely not the intent of Chapter 91, it has created a landscape where private property owners seek to protect a coastline (or a property line from change) and mitigate damages rather than a reality where coastlines adapt to be more resilient to coastal hazards and future change (Summers et al. 2018). Orrin H. Pilkey and J. Andrew G. Cooper note in *The Last Beach* that “a natural beach never needs protection from the forces of nature; it is perfectly adapted to cope with anything that is thrown at it. Without the impact of humans, a beach will always be there and in good shape, although after a storm, it might be a different shape or in a new location” (Pilkey and Cooper 2014, 41). The coastlines ability to adapt, and shift has been permanently altered, and actions such as shoreline hardening have protected the private property owner’s right to own the tidelands. However, beyond ecological impacts,

and damage to the littoral system, shoreline hardening has led to a loss of Commonwealth-owned tidelands and public access to the coastline.

Over the years, public opposition to shoreline hardening has become increasingly commonplace, in part, due to hard stabilization structure's impact on public tidelands (Griggs 2005). Gary B. Griggs notes in *The Impacts of Coastal Armoring* that public concerns "revolve around the issue of to what degree should private property owners be allowed to impact public beaches as they attempt to protect their own property" (Griggs 2005, 16). While hard stabilization prevents shoreline erosion for a coastal property owner and protects development, it exacerbates other problems such as "coastal squeeze or beach narrowing and eventual loss on chronically retreating shorelines" (Tavares, Fletcher, and Anderson 2020, 1). Coastal squeeze leads to the loss of publicly owned tidelands while the tideland's landward seawall and breakwaters are maintained. In locations such as Marblehead Neck in Marblehead, MA, the prevalence of shoreline hardening is so significant, it is likely that one could not walk around the entirety of the tidelands at MLW without encountering a barrier in the form of a hardened structure (Figure 11).



Figure 11. *Privately-owned structures along Marblehead Neck, in Marblehead MA (Data Layer: Massachusetts Office of Coastal Zone Management).*

In a situation such as Marblehead neck, the protection of private tidelands significantly impacts the public's ability to fish, fowl, and navigate. Public tidelands are adversely impacted due to

shoreline hardening, and the loss of public tidelands due to maintaining private property rights under Chapter 91. This situation is in direct opposition to the intention of Chapter 91, and under the way that the statute currently operates the Commonwealth is failing in its role as the trustee of the tidelands.

The loss of public tidelands would lead one to believe that there must be significant benefits of coastal hardening to justify the coastal squeeze. However, one study found that the cost of protecting land at each study site averaged about 33 times the marginal benefit (Mendelsohn and Zheng 2020). Additionally, the study found that the “extra height required to stop a 100-year storm returns about three cents in flood benefits for every dollar spent on protection. It is generally not an attractive proposition to protect American cities from major tropical cyclones using seawalls. Seawalls are too expensive to stop the storm surge from major tropical cyclones” (Mendelsohn and Zheng 2020, 9). This data presents the twisted cost-benefit reality of shoreline stabilization practices. Techniques such as hardening and beach nourishment do not distribute costs and benefits evenly, and within each project, it is essential to understand who the beneficiaries are (Coburn 2012; Mendelsohn and Zheng 2020). For example, coastal property owners receive 60–90% of all beach nourishment benefits, even though most projects are funded using tax dollars (Coburn 2012). The proposition of protection remains problematic; shorelines will continue to change and the probability of preserving coastlines as they appear today is statistically impossible.

Protection of some form exists for coastal property owners, but at what cost - and who pays that cost - the property owner, the Commonwealth, the public, or the environment? If protecting coastlines is seen through the lens of reducing the environmental damage due to

anthropogenic activities, then protecting coastlines needs to be focused on safeguarding and improving the ecosystem services that coastlines provide. The following chapter examines the regulatory landscape in Massachusetts, which focuses on environmental preservation, providing additional oversight to the tidelands and shoreline stabilization practices.

Chapter 4: Coastal Protection Regulations in the Commonwealth

While Chapter 91 establishes ownership in the tidelands, projects on private tidelands must meet “various state and municipal policies and codes such as local zoning ordinances and bylaws” in the Commonwealth (Moran, Miller, and Shelley 2019, 9). The Coastal Zone Management Act (CZMA) and the Wetlands Protection Act (WPA) also manage the tidelands and what techniques are taken to stabilize the shoreline. A recent report *Climate Change & the Massachusetts Public Waterfront Act* (2019), published by the Conservation Law Foundation, notes that these state and municipal programs “may impose different or more stringent requirements” than Chapter 91 (Moran, Miller, and Shelley 2019, 9).

Coastal Zone Management Act

The Coastal Zone Management Act (CZMA) is administered by National Oceanic and Atmospheric Administration (NOAA). The Act aims to “preserve, protect, develop, and, where possible, to restore or enhance the resources of the nation’s coastal zone” (NOAA Office for Coastal Management 2022). The CZMA explains a national interest in “effective management, beneficial use, protection, and development of the coastal zone” (16 U.S.C. § 1451. Sec. 302). The federal government determined it should not manage the nation's coasts or tell the states how to manage them; in turn, Congress enabled states to engage in more integrated coastal management (Thompson 2013). Participation by individual states under the Act is voluntary. Massachusetts was the first state on the eastern seaboard with a federally approved coastal program through the Commonwealth's Act Relative to the Protection of the Massachusetts Coastline (Massachusetts Office of Coastal Zone Management 2011). The Office of Coastal Zone

Management (CZM) was created to administer state regulations and is located within the Commonwealth's Executive Office of Energy and Environmental Affairs (EEA). The Massachusetts Legislature established the EEA in 1975, regulating the Commonwealth's coastlines through the Massachusetts Environmental Policy Act Office (MEPA) and the Massachusetts Department of Environmental Protection (MassDEP). CZM's mission is to “balance the impact of human activities with the protection of coastal and marine resources through planning, public involvement, technical assistance, research, and sound resource management” (Massachusetts Office of Coastal Zone Management 2011, 2). Since the Act was adopted due to increased pressures from development in the tidelands, it works to manage the land-sea connection through an ecological lens (Kittinger and Ayers 2010).

The word “protection” is found throughout the CZMA; in this instance, protecting the environment is the priority. In the CZM Final Environmental Impact Statement, it was noted that “Over the long run, the Massachusetts CZM Program will protect the coastline's natural riches and ensure for all the residents of the Commonwealth that the environmental and economic value of the Massachusetts coastal zone will be sustained, and even enhanced” (National Oceanic and Atmospheric Administration 1978, 4). CZM intends to protect the ecosystem services of the Commonwealth due to their intrinsic and economic value, especially since the natural resources provided by the coastal zone are significant economic resources in the Commonwealth (National Oceanic and Atmospheric Administration 1978).

The Commonwealth is making significant strides towards adapting the coastline to be more resilient to climate change through grant programs such as the Commonwealth's Coastal Resilience Grant Program and the Municipal Vulnerability Preparedness Action Grants. Since

the grant programs are focused on the community level, municipalities must meet the guidelines of the programs to receive funding to complete projects in coastal communities. To be eligible for funding, strategies for mitigating risk under these programs strongly encourage approaches that utilize NBS and/or managed retreat to address climate change impacts and coastal hazards. In 2022 alone, the MA CZM Coastal Resilience grant program has included investment in projects such as salt marsh restoration at Jackknife Beach in Chatham, MA (\$141,675); phased retreat construction project at Nauset Beach parking lot in Orleans, MA (\$1,000,000), and a nature-based shoreline restoration project in the town of Braintree, MA (\$772,580) (Office of Coastal Zone Management 2022) (Figure 12).



Figure 12. Nature based solutions project in Watson Park, Braintree, MA. Before (left) and after (right). The project is funded by a CZM Coastal Resiliency Grant (Town of Braintree 2022).

Wetlands Protection Act

In addition to CZM, the coastal zone is also managed through the Wetlands Protection Act (WPA), which “protects wetlands and the public interests they serve, including flood control, prevention of pollution and storm damage, and protection of public and private water supplies, groundwater supply, fisheries, land containing shellfish, and wildlife habitat”

(Massachusetts Department of Environmental Protection 2022, par. 4). Massachusetts was one of the first states in the country to adopt wetlands protection laws in the early 1960s; in part, because since colonial times, almost one-third of Massachusetts' wetlands have been destroyed (Commonwealth of Massachusetts 2022a). Due to a history of wetland loss in the Commonwealth, the WPA seeks to have a “no net loss of wetlands” policy, and it aims to avoid impacts whenever possible and minimize and mitigate unavoidable impacts in wetlands (Massachusetts General Laws c.131, sec. 4). The law seeks to protect all wetlands, land in the 100-year floodplains, and land under water bodies (Commonwealth of Massachusetts 2022a). Wetlands include areas directly adjacent to the ocean, including beaches, salt marshes, dunes, coastal banks, rocky intertidal shores, and barrier beaches (Commonwealth of Massachusetts 2022a). A WPA permit is required for any activity within 100-year floodplains or directly impacts protected wetlands resources (Meyer 2005). The WPA oversees the permitting process of shoreline stabilization practices along the coastline. With strict regulations that reduce the hardening of the shorelines, “no new bulkhead, revetment, seawall, groin or other coastal engineering structure shall be permitted” (Commonwealth of Massachusetts 2022a).

MassDEP oversees the administration of the law, developing regulations and policies; however, the WPA delegates primary responsibility for implementing the statute to the state’s 351 cities and towns (Massachusetts Office of Coastal Zone Management 2011; Meyer 2005). Under the WPA, local conservation commissions, comprise of a volunteer board appointed by local selectmen or city council (Commonwealth of Massachusetts 2022a). The role of municipal conservation commissions is to seek to certify that proposed projects will “not alter resource areas and the public interests they provide by reviewing projects on a case-by-case basis

according to regulations” (Massachusetts General Laws c.131, sec. 4). Conservation commissions administer state standards within the jurisdiction and oversight of the state with considerable discretion within the law to establish the details of a permit. Conservation commissions may implement town wetland bylaws set through the town meeting process, which are outside the jurisdiction and oversight of the state (Meyer 2005). Bylaws are carried out through a provision of the Massachusetts Constitution known as the “home rule,” which allows conservation commissions the right to pass their local bylaws so long as they are more stringent than corresponding state law (Meyer 2005). More than 100 Massachusetts communities have local wetlands protection bylaws, which gives conservation commissions influence over the action taken in the tidelands (Commonwealth of Massachusetts 2022a).

Reactive Regulations

The CZM and the WPA were created in direct response to increased population growth, economic expansion, and an increased need to manage anthropogenic impacts on tidelands (Massachusetts Office of Coastal Zone Management 2011). However, the regulatory framework is designed to be reactive to development rather than adapting coastlines to the threats presented by climate and coastal hazards (Davenport, Kirk, and Bowden 2022; Fisichelli, Schuurman, and Hoffman 2016). Under the current system, the tidelands are preserved for their ecological value or altered by coastal property owners for their individual needs. Since the property owner funds shoreline stabilization projects on their private property, the homeowner’s values and propensity for risk are at the forefront of critical decision-making about the Massachusetts coastline.

An example of an agency policy that is reactive rather than forward-thinking is the WPA exemption of coastal engineering structures that have filed a Notice of Intent filed before August 10, 1978 (Commonwealth of Massachusetts 2022a). In these cases, structures can be constructed or rebuilt along the coastline, so long as structures are built to minimize the adverse effect, using the best available measures; and there is no method of protecting the building other than the proposed coastal engineering structure (Commonwealth of Massachusetts 2022a). This exemption essentially allows for the vesting of coastal hardening, reinforcing the private property owner's regime and requiring that the rules apply to some properties and not others. Vesting, often wrongly referred to as "grandfathering," is problematic; it allows individuals to keep operating under existing expectations even when new rules are in place (Greenblatt 2013). When rules lack consistency, they create implementation challenges for the Commonwealth. Vesting under the Wetlands Protection Act will impact the progress of NBS that follow an ecology-first model that does not have a legacy of stabilization. Although the effect of a single property owner hardening their shoreline may be comparatively small, the cumulative impact of multiple property owners hardening the shoreline can result in significant habitat degradation with associated ecosystem effects (Currin, Chappell, and Deaton 2010).

Since some private property owners are permitted to construct or rebuild hardened structures, the risk of erosion is unequally distributed among coastal property owners rather than through a comprehensive planning framework that considers cumulative impacts and the co-benefits of NBS. Coastal development continues, and when a private property owner's coastline is threatened by erosion, the expectation is that they may take action to reduce their

risk. Under this framework, erosion risk typically results in flanking of neighboring coastal property owner's shoreline, a loss of publicly owned tidelands, and reduced access to the beach (Kittinger and Ayers 2010). The current model in the Commonwealth under Chapter 91, CZM, and the WPA, shoreline change appears to look like Figure 13, where the coastal private property owner's risk is reduced.

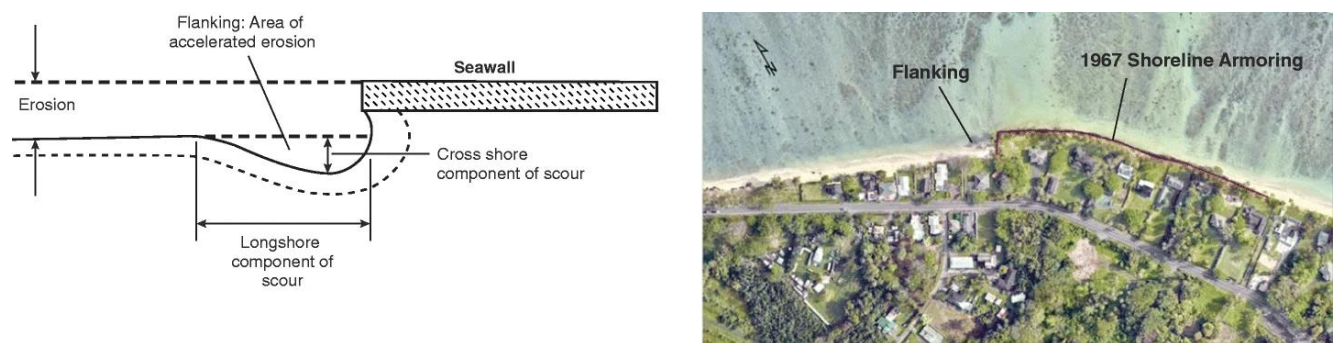


Figure 13. Coastlines adjacent to a seawall are subjected to increased erosion due to the hardened shoreline's reductions in sand availability (Summers et al. 2018).

In terms of shoreline stabilization, the current regulatory landscape in the Commonwealth manages persistent issues such as coastal erosion, on a case-by-case basis, reactive to the requests of individual coastal property owners (Kittinger and Ayers 2010). While CZM and the WPA seek to manage the tidelands through a lens of reducing damage from development, there is a gap in the regulatory landscape that needs a forward-thinking approach to address emerging threats such as future sea-level rise (Kittinger and Ayers 2010). Davenport, Kirk, and Bowden (2022) note that “in order to meet the growing threat of climate change along the Massachusetts coast, the Commonwealth must update its laws and regulations to reflect changing climate conditions such as anticipated sea level rise and increased frequency and severity of extreme weather events” (Moran, Miller, and Shelley 2019, 1). A model established by colonial ordinances is not equipped to cope while the shore

continues to erode, and coastal hazards increase in frequency. It is time for the statute to “come ashore” again, which is explored in the next chapter of this thesis.

Chapter 5: Shoreline Stabilization Focused on Adaptation

Although decision-making regarding shoreline stabilization in the Commonwealth is still skewed towards a coastal property owner's self-interest and personal gain, the retreat of shorelines needs to be managed in a way that allows shorelines adjust to changes over long periods. Management of the tidelands must be focused in preserving the public tidelands rather than the private tidelands, which was the true intention of Chapter 91 (Barnett et al. 2014). Methods such as NBS offer alternatives that allow a coastline to become more adaptable to the threats from climate change and coastal hazard. The management of the shoreline through a coastal adaptation approach shifts towards a dynamic response where multiple stressors are addressed under future scenarios (Cheong et al. 2013). Under this approach, "robust, resilient and cost-effective solutions that combined strategies can prepare people for a highly uncertain coastal environment in the future" (Cheong et al. 2013, 787). When shorelines are stabilized, methods should be used to manage future storm waves and water velocities rather than managing daily tidal inundation (Brashear 2022). In reference to Chapter 91, Moran, Miller, and Shelley (2019) noted that:

The prevailing practice in coastal development and tidelands licensing has been and continues to be to design and license structures according to the climate patterns and weather events of the past, rather than those observed in the present or anticipated in the imminent future. This backward-looking orientation has implications not only for public health and safety, but also for the resilience of our economy and the ability of the public to access waterfront lands for recreation and other purposes to which it is entitled (Moran, Miller, and Shelley 2019, 3).

In locations where a coastal property owner seeks to harden a shoreline, the ability of a coastline to adapt needs to be prioritized in the regulatory framework and coastal hardening needs to be approached through a framework that addresses the purpose and need of the

hardening (Brashear 2022). A framework that prioritizes adaptation would need to address not only the risk reduction for coastal property owners but also how a potential hardening addresses other issues such as social vulnerability, loss of the public tidelands, environmental degradation, and/or resilience to climate change. An adaptation framework to shoreline stabilization has been gaining momentum in recent publications, including strategies to address future threats to the coastline rather than supporting a private property owner regime (Davenport, Kirk, and Bowden 2022; Kittinger and Ayers 2010; Moran, Miller, and Shelley 2019).

Anti-Hardening Policy

Given the considerable amount of infrastructure and development along the coastlines, the Commonwealth will continue to be at risk from coastal hazards and climate change. However, “risk is best reduced by limiting exposure to coastal hazards” (Rabenold 2013, 294). Future strategies by the Commonwealth to manage the tidelands should focus on how to create incentives to reduce risk, such as managed retreat. Currently, “risks loom large with potential damages” from climate change and coastal hazards; however, coastal property owners are more focused on holding the line, utilizing the vesting they are afforded under the WPA (Beasley and Dundas 2021, 2; Tavares, Fletcher, and Anderson 2020). Gittman et al. note that “in areas where armoring is strongly preferred, more robust and restrictive policies against future shoreline armoring may be needed to prevent a tyranny of small decisions from driving coastal habitat loss” (Gittman et al. 2021, 10).

In their paper *Shoreline Armoring, Risk Management, and Coastal Resilience Under Rising Seas* Kittinger and Ayres (2010) discuss the idea of states such as the Commonwealth

adopting a “robust anti-armoring policy that effectively passes the hazards associated with coastal development from the public to the littoral property owner and creates incentives for risk reduction” (634). This approach would require that all coastal property owners be equal in their ability to modify the tidelands they control. Under the Kittinger and Ayers model, hardening would only be used in situations where the project benefited the public interest, such as critical infrastructure, historical landmarks, and vulnerable populations (Kittinger and Ayers 2010).

Since hard stabilization would be prohibited, an anti-hardening model could increase the use of various NBS, as homeowners would likely still be interested in holding the line. The more frequent use of NBS would lead to the “conservation and restoration of valuable wetlands along shorelines that may have otherwise been hardened” (Gittman et al. 2021, 10). The frequent use of NBS could increase the awareness of multiple stakeholder groups who currently modify the coastline's changing social norms (Gittman et al. 2021). Additionally, the increased use of NBS will likely influence academic research, increasing service provider expertise (Restore America's Estuaries 2015).

While there is a precedent for an anti-hardening policy (North Carolina and Washington), it would reduce the barriers to implementing NBS, reduce coastal squeeze, and has ecological benefits, the policy is not without challenges (Gittman et al. 2021; Restore America's Estuaries 2015). The primary challenge facing this policy is that it would not be popular among coastal property owners and is not politically advantageous (Gittman et al. 2021). For a politician who needs the popular vote to retain office, a policy like this would require considerable influence, evidence, and support to take place. Additionally, further research would need to be conducted

to explore the impacts of providing more opportunities for the Commonwealth to retain control of the tidelands. This policy would give more flexibility to the state to determine need, and with that may leave the door open to the misuse of the policy by local government officials and WPA conservation commissions.

Regulating Nature-Based Solutions Using Separate Design Standards

Currently, in the Commonwealth, NBS are regulated and permitted under the same standards as hardened structures, a system designed to minimize direct impacts to protect the tidelands and their resources (Davenport, Kirk, and Bowden 2022). “A strong regulatory preference to avoid resource impacts may be unintentionally making living shorelines more difficult to permit than hard structures and incentivizing traditional hard structures, even though hardened shorelines are more likely to place resources at risk when cumulative impacts and future environmental conditions are considered” (Davenport, Kirk, and Bowden 2022, 3). While avoiding a mitigating for adverse impacts to the tidelands from development pressures it important, the current framework does not recognize how NBS differ in their stabilization practices from the approaches utilized by hard stabilization practices.

An example of this is the use of fill in the tidelands. Since the use of fill significantly changes the existing tidelands, the practice is heavily regulated under Chapter 91 (Commonwealth of Massachusetts 2022c, 91). Fill is regulated under Chapter 91 through the lens of managing the development and is written into the regulation to “protect an existing structure from natural erosion or accretion, or to protect, construct, or expand a water-dependent use” (Massachusetts General Laws, c. 91, Moran, Miller, and Shelley 2019). Fill for a

hard stabilization structure, is likely to serve a different purpose than it does for a soft stabilization practice. The report *Climate Change & the Massachusetts Public Waterfront Act* (2019) describes how Chapter 91 impacts the use of such approaches noting that MassDEP's:

Current practice is to classify projects that include both non-water-dependent and water-dependent or accessory to water-dependent uses as non-water-dependent use projects. Therefore, any non-water-dependent use project (like a residential or commercial building) intending to incorporate a water-dependent climate adaptation component (like a living shoreline or a berm) would need to obtain a separate license for the water-dependent component in order to propose the introduction of new fill. (Moran, Miller, and Shelley 2019, 28).

This example highlights how the regulation restricts the actions taken to adapt to the shoreline.

Existing natural marshes are impacted by the current hardened shoreline, causing a sediment-starved system may require additional fill and vegetation to make the coastline more adaptable; however, these practices are managed under the same restrictions as a new seawall (Davenport, Kirk, and Bowden 2022; Ganju 2019). Since there are no one-size fits all design standard for NBS approaches, there are challenges regarding how to include the practices in the policy framework (Neal et al. 2018; Santosh Kumar, Sannasiraj, and Murali 2021). However, in the face of climate change, NBS may be a more sustainable and cost-effective solution that offers opportunities for co-benefits to society, such as adaptation to coastal hazards and increased filtration of nutrient runoff (Kumar et al. 2020).

Additional analysis is needed on integrating NBS into the policy landscape and exploring how the permitting process creates barriers to using NBS (Restore America's Estuaries 2015). One component that needs to be explored further is local conservation commissions' role in creating inequities through a lack of understanding of NBS (Restore America's Estuaries 2015). Local conservation commissions wield considerable influence at the local level in managing

shoreline stabilization practices. Since conservation commissions consist of a volunteer board appointed by local selectmen or city council, there are significant knowledge gaps since these individuals are not likely to be coastal scientists, making it challenging for this group to regulate the tidelands and understand the implications of various shoreline stabilization practices. The issues at this level can include personal bias and a lack of consistency in implementation and education (Neal et al. 2018).

Address Homeowner's Perception of Risk

The National Flood Insurance Act created the National Flood Insurance Program (NFIP), which is now managed by the Federal Emergency Management Agency (FEMA), serving as the primary provider of flood insurance for much of the coastal zone (Neal et al. 2018). One of NFIP's goals is to increase the flood insurance participation rate through programs that subsidize premiums, provide commissions for selling flood insurance, and require that high flood-risk properties purchase flood insurance (McShane and Yusuf 2019). Increased flood risk for coastal property owners is managed through FEMA's floodplain maps which are the bases for insurance rates (Neal et al. 2018) (Figure 14). These maps include predicted levels of storm-surge flooding based on records and models of past events; however, the impact of future events, the variables due to sea-level rise, and erosion rates are not included (Moran, Miller, and Shelley 2019; Neal et al. 2018).

National Flood Hazard Layer FIRMette

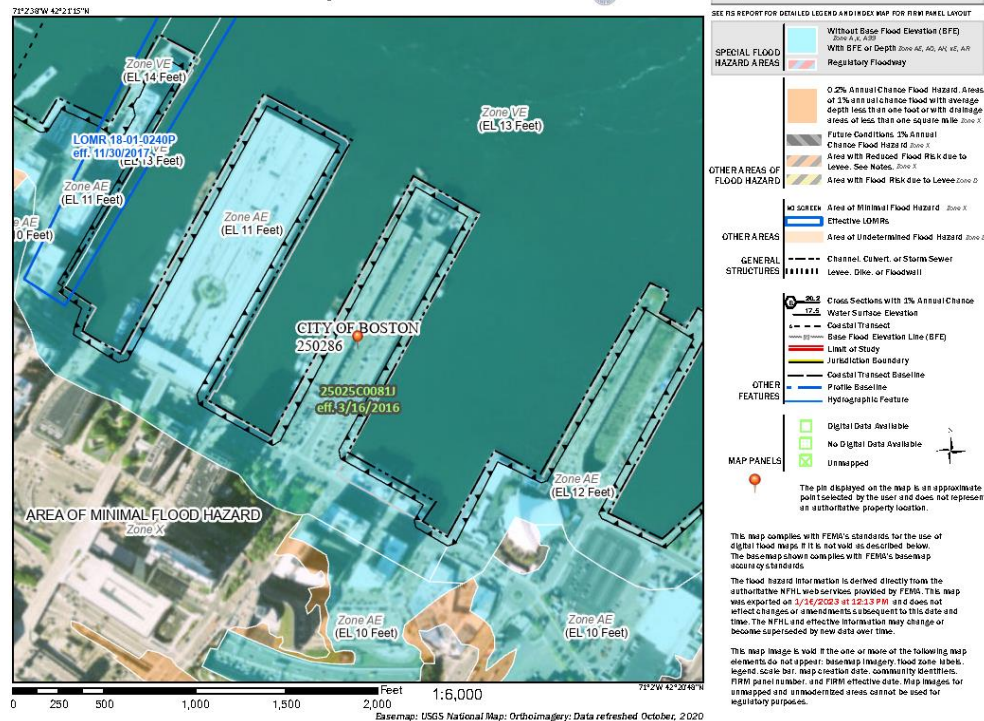


Figure 14. Example FEMA FIRM map in the City of Boston in the Fan Pier section of the Seaport (FEMA 2023).

Failing to include these metrics means that properties may not be adequately insured and may be more vulnerable to hazards than currently assumed. For example, “high erosion rates will shift the potential storm-surge zone landward and allow bigger waves to penetrate farther inland during storms (Neal et al. 2018, 23).

Additionally, NFIP has earned much criticism and has been referred to as an ineffective program by encouraging development in hazardous areas (Neal et al. 2018) through its policies. Currently, the NFIP owes approximately \$21 billion to the U.S. Treasury, even after Congress canceled \$16 billion of NFIP debt in October 2017, when Congress made it possible for the program to pay claims from recent tropical cyclones such as hurricane Sandy (Congressional

Research Service 2021). Low flood insurance participation rates and inadequate management of flood losses are the root cause of NFIP's debt (McShane and Yusuf 2019).

The Federal National Flood Insurance Act has created an ineffective program similar to beach nourishment. It creates a false sense of security for homeowners, as it must accurately represent risk. Barriers to development in floodplains are decreased through NFIP due to the availability of flood insurance which limits losses and creates minimal incentives for property owners to take measures to reduce their vulnerability to flooding (Burby 2006; Rosenbaum and Gary 2006). Raymond J Burby describes in their paper *Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing about Wise Governmental Decisions for Hazardous Areas* that “federal policies have sought to make areas at risk from natural hazards safe places for urban development by reducing the degree of hazard and by shielding hazard-area occupants from financial risks of loss. Over time, these policies have facilitated the development of these areas” (Burby 2006, 178). Figure 15 shows the development in the floodplain from Figure 14's flood hazard layer, which includes development in FEMA's AE Zone, which as FEMA explains are “Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage” (FEMA 2023, 1).



Figure 15. Fan Pier, Boston, MA - 1982 (Left) vs. 2017 (Right) where coastal infrastructure has increased at an accelerated pace along the coastline in the flood zone (Boston Magazine 2020).

The NFIP reduces individuals' perceived risk of living in the coastal zone, and more importantly, it impacts the landscape of shoreline stabilization at the local government level. Local governments have less incentive to prioritize using their limited resources on disaster preparedness, mitigation, response, and recovery, given that the perception is that the NFIP will bail out individuals through flood insurance (Burby 2006). In a 2016 interview, the outgoing Director of FEMA noted that “As long as the government (taxpayers) pays the tab for disaster recovery, states and local governments have little incentive to move development out of harm's way” (Neal et al. 2018, 22). This directly impacts the interest of coastal property owners and local governments to utilize a managed retreat approach to mitigate sea level rise, coastal flooding, and erosion.

Chapter 6: Conclusion

In their book *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants*, Robin Wall Kimmerer (2013) remarks on how we as individuals impact the natural world; they note that “restoring a habitat, no matter how well-intentioned, produces casualties. We set ourselves up as arbiters of what is good when often our standards of goodness are driven by narrow interests, by what we want” (92). Thinking through the perspective of a Citizen of the Potawatomi Nation, about being “arbiters of what is good,” leads one to reflect on the historical development of the tidelands (Kimmerer 2013). The tidelands as society know them today are a direct result of the colonization of the lands where the Commonwealth lies and the establishment of Chapter 91, which divided up the stewardship of the land and alienated our relationship with the coastline as a system.

The long-term impacts of Chapter 91 have led to increased shoreline hardening, the loss of public access to the tidelands, and environmental degradation. Allowing coastal property owners to be the arbiters of what is good in the tidelands has created a property right regime where interest is focused on personal use and risk. The casualties produced in this system are often the species that occupy the coastline, the public, and society's vulnerable populations. CZM and the WPA, while well-intentioned, were designed to be narrowly focused on avoiding and minimizing impacts on the coastline. Which, in some cases, has led to the staled adaptation of the coastline.

The current state of stabilization practices in the tidelands could be described as a "wicked problem" in the field of Environmental Science (Balint et al. 2011, ix). "Wicked problems are characterized by a high degree of scientific uncertainty and a profound lack of

agreement on values. Further, even though there is no correct decision in the case of a wicked; problem, the manager must make a decision... By definition, a wicked problem has no optimal solution, the decision maker must seek other measures of success" (Balint et al. 2011, ix). The manager(s) in the case of this wicked problem are the regulatory agencies and politicians in the Commonwealth. To Kimmerer's point, the wicked problem will produce casualties, no matter how well-intentioned. However, as this thesis explored, the scientific uncertainty regarding NBS is decreasing, and the managers of this wicked problem must examine how the current regulatory framework is hindering adaptation. Narrow interest in the tidelands needs to be focused on actions that focus on ecological restoration and reducing social vulnerability. The future of Chapter 91 needs to include the role of coastal hazards and climate change on the tidelands and allow the evolving science on best practices to assist in adapting coastlines. The managers must evaluate how the system has operated since the Mass Bay Colony, recognize the impacts of the coastline partitioning, and seek new measures of success that include reducing vulnerability for the casualties of the current system.

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