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New York City's Rising Sea Level and Coastal Erosion: Approaches to Resiliency

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By

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Abstract

This paper examines New York’s rising sea levels and coastline erosion to underpin the state’s need to move from an adaptive climate approach to a more robust and proactive one. Longstanding responses to the world’s climate disaster have historically taken adaptive approaches, which act as reactive rather than proactive responses in climate initiatives. Strong “mitigative” responses understand that the current course of climate change is not halting anytime soon, and we should expect the intensity of weather variables to grow. There is a need for responses that go beyond the immediate and address the long-term effects of climate change. Chapter One provides data on the weather, establishing the presence of predictable extreme weather cycles and their impact on New York's coastline and oceanic health. Today's data shows that extreme weather is growing exponentially. Models predicting increasing weather intensity have continued to represent our best prediction of future climate scenarios. Chapter Two explores the historical responses to sea level rise and coastal erosion and our approach to climate change throughout history. Chapter Three compares the economic strain of current and recent climate solutions and the analyses of adaptive strategies in addressing sea level rise and coastline erosion while touching on mitigative philosophy. Chapter Four analyzes the policy and politics currently engaged in climate initiatives, how current agencies are addressing the issue of rising sea levels and erosion and the planning around enacting climate response. Lastly, Chapter Five introduces proposed climate response initiatives for New York's climate disaster. Implementing approaches to resiliency without upheaving the “status quo” and understanding the impact of adaptive versus “mitigative” measures in addressing New York’s rising sea level and coastal erosion.

Keywords: Climate Change, Erosion, Adaptative, Mitigative

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I want to take a moment to cite New York City's CHR land acknowledgment for the displacement of the Lenape people:

> "The New York City Commission on Human Rights ("Commission") acknowledges the land politically designated as New York City to be the homeland of the Lenape (Lenapehoking) who were violently displaced as a result of European settler colonialism over the course of 400 years. The Lenape are a diasporic people that remain closely connected with this land and are its rightful stewards. We also recognize that New York City has one of the largest urban Native American / Indigenous populations in the United States."

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"Accuse not nature: she hath done her part; Do thou but thine."

-John Milton, Paradise Lost Book VIII

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Introduction

Growing up in Santa Cruz, California, and spending my summers in Bronxville, New York, my childhood days were steeped in the unfettered beauty of America's nature. From the sprawling redwood coast to the rustic Appalachians, I was fascinated by the intricacies of so many different organisms, all contributing to the grand tapestry of life. Yet, as I grow older, that same nature at times bears little resemblance to the scenes that graced my youth. Today, we face various challenges threatening our existence as we continue to reshape our planet in unimaginable ways. Woods once inhabited by beneficial organisms are now overrun by invasive species and are dying. Pristine beaches and coastal cliffs crumble under the relentless force of erosion. Coral reefs and kelp forests wither away while oceans grow acidic and warm. Vast swaths of land are razed and burned. All the while, we continue to spew metric tons of CO_2 into our atmosphere. Our collective attitude towards this front has been little more than passivity until recently. A shift must occur, lest we seek to resign the mantel of humanity to the annals of time, for this is a problem that presents an existential crisis for all living organisms.

This thesis focuses on two critical climate issues confronting New York City: rising sea levels and coastal erosion. It seeks to shed light on initiatives that offer potentially lasting solutions that use a framework combining both regenerative and "mitigative" approaches. In the chapters that follow, we will delve into these issues and explore their respective potential remedies.

Understanding the Challenge: Chapter One lays the foundation for our exploration into New York City's Sea level rise and erosion. Chapter one looks at key variables of extreme climate processes, setting the stage for expected climate scenarios in the future and their impact on New York's coastal areas. We will examine how these challenges persist as we fall short of addressing climate goals.

Historical Perspectives and Initiatives: In Chapter Two, we dive into the historical responses and interactions with sea level rise and coastal erosion, particularly in densely populated regions like New York City that are at or below sea level. We analyze the initiatives that have been employed and their effectiveness. These metropolitan areas offer key insight into how these responses and actions may translate into initiatives or lessons for climate resiliency in New York.

The Economic Toll: Chapter Three focuses on the economic strain caused by these climate events. In addition, we will analyze major initiatives posed to try to halt climate problems troubling New York City and their efficacy in action.

Policy, Politics, and Sustainability: In Chapter Four, we navigate the policy and politics surrounding climate initiatives. We explore the actions of local organizations dedicated to making a measurable difference and examine the existing models contributing to a sustainable framework. This agency and organizations at the forefront of climate resiliency offer us insight into the robust and abstract ways of reducing climate change. These initiatives often provide frameworks that can be applied or scaled to reach and encompass broader climate initiatives.

Towards a Lasting Future: Finally, Chapter Five proposes localized responses to New York's climate challenges, aiming to address the aggregate of climate problems by implementing a “mitigative” strategy framework, relying on a combination of regenerative initiatives to gradually restore lost coastlines and mitigate sea level rise using hybird solutions. Through this thesis, we embark on a journey of discovery and action, striving to illuminate the path towards a more resilient and sustainable future for New York City and the world at large.

Chapter 1: *What is the Damage?*

Understanding the Problem: Coastline erosion and rising sea levels (Referred to as SLR and CE) are urgent issues facing New York City (referred to as NYC). These problems affect large areas of land situated near the oceans and present a unique problem due to the inclusion of a major metropolitan area. These problems are usually normal aspects of climate and can be reacted to properly in the past. However, due to the exponential acceleration of human-induced climate change, problems such as SLR and CE are currently being expressed more and more drastically in ways that simply reacting to the threat will not properly mitigate it. The mayor's office of New York has stated:

> Sea level in New York City has already risen at least 18 inches since the 1850s and could rise as much as another 6 feet by 2100. Sections of the city's coastline will be subject to daily tidal flooding by the 2050s. Some low-lying neighborhoods are already experiencing chronic tidal flooding due to astronomical high tides. (City of New York 2023)

To present a clearer perspective: 18 inches in 173 years, and 4x that amount in another 77 years. The graph below demonstrates the affected area of coastal flooding from sea level rise of about 31 inches by 2050:

Figure 1: SLR Affected Area

The influx of salt water can destroy the majority of Lower Manhattan, East Village, Greenpoint, Long Island City, and other areas of the five boroughs if not addressed properly. In addition to this, as sea levels rise, the increased threat of coastal erosion becomes ever more prevalent as a higher sea level pushes the coastline further inland, causing erosion to occur closer and closer to populated areas. The Hazard Mitigation guideline of New York states:

> Coastal erosion can damage public and private property and infrastructure by bringing the water's edge closer. Unchecked, erosion may eventually result in structures becoming flooded or the ground beneath them giving way. This could undermine foundations, resulting in structural failure or collapse. (City of New York 2021, 61).

Areas of New York City are threatened to be lost to SLR and CE due to the undermining of infrastructure and the inclusion of salt water. The two images below show an area of New York City's suburban coastal erosion, the first taken in 1995 and the second in 2013:

Figure 2: City of New York Hazard Mitigation: CE After

In addition, by further breaking down these implications of threats to NYC's coastline, we can elucidate the effects we will see in response to these vulnerabilities. "Coney Island and the Rockaways are examples of New York City's coastline, which has extensive beaches and built-up areas. These areas are maintained for public recreational use, while the Gateway National Recreation Area is an important nature reserve and bird migration stopover site. Under sea level rise and associated enhanced coastal flooding, beaches require additional sand replenishment to be maintained" (Rosenzweig et al. 2010). Losing recreational land areas in New York poses a twofold effect, both economically and environmentally, more significant than the immediate response of lost land and the financial undertaking of damage control. The loss of land used for recreational activities can prevent the economic stability of beach tourism from faltering, affecting local communities and economies. In addition, the loss of migrating bird reserves affects the local ecosystem.

Beyond Mere Damage: Removing one species can induce unforeseen consequences, from the die-off of native plants and species to the incursion of pests and other consequences. "The disappearance of certain bird species disrupts pollination and seed dispersal mechanisms, leading to a cascading effect on plant populations, affecting the entire ecosystem's resilience and function. This chain reaction illustrates how birds are integral to maintaining ecological communities' structural integrity and functional dynamics" (Sekercioglu et al. 2004). This multifaceted effect from SLR and CE demonstrates the severe vulnerability our communities are subjected to from the effects of climate change. Affects from SLR and CE stem beyond mere damage and influence more significant functions of nature and society.

Expanding on the vulnerabilities identified for New York City's coastlines due to sea level rise and coastal erosion, it is crucial to consider the broader social implications of these environmental changes, particularly through the lens of environmental justice. The concept of environmental justice is particularly relevant in this context, as it underscores the disproportionate risks that coastal communities, often the most vulnerable, face from climate change impacts due to their physical and socio-economic positions. A significant insight from research suggests that 'vulnerable populations in coastal areas experience a dual burden: they are most likely to face the direct impacts of sea level rise and are less capable of recovering from its impacts due to limited resources' (Herreros-Cantis et al. 2020). This disparity underscores the environmental injustice where the least equipped communities bear the most severe consequences of climate change. The implications of sea level rise and coastal erosion extend beyond the immediate loss of land and financial challenges associated with damage control. The research highlights that 'floodplain development and population growth increase flood risk regardless of floodplain expansion' (Herreros-Cantis et al. 2020). This indicates that the socio-economic fabric of the communities within these vulnerable areas is intricately linked to their geographical and environmental contexts, impacting local economies and ecosystems in profound ways.

Furthermore, it is crucial to address the 'double jeopardy' faced by certain community districts where increases in exposure coincide with increases in vulnerability due to shifts in racial demographics and income levels. This phenomenon exacerbates the risks and challenges faced by these communities, underscoring the urgent need for targeted policy interventions that address both the environmental and socio-economic dimensions of sea level rise and coastal erosion. These interventions could include measures to enhance the resilience of vulnerable communities, promote equitable access to resources, and mitigate the adverse effects of climate change.

Expanding on the vulnerabilities of urban center from SLR and CE, the interconnection between Urbanization and its impact on extreme weather events is essential. Due to their dense infrastructure and altered land surfaces, urban areas significantly influence local climatic conditions. This effect of Urbanization is particularly evident in how urban settings amplify the frequency and intensity of extreme precipitation, which contributes to the increased vulnerability to coastal erosion and sea level rise.

A study underscores the magnitude of this impact: "Urbanization can strongly increase the frequency and intensity of extreme urban precipitation. Frequency increases far more than intensity, by +16% (11%–22%) for 1-year daily extremes, and +26% (11%–41%) for 1-year hourly extremes, downwind of city centers" (Marelle et al. 2020). This enhancement of precipitation due to Urbanization adds another layer of complexity to the challenges posed by SLR and CE. As cities expand and more surfaces are paved and built upon, the natural land's ability to absorb rainfall diminishes, leading to higher runoff and exacerbated flood risks.

The resultant increase in runoff can expedite coastal erosion as more water is channeled into the sea, carrying with it land materials that would otherwise bolster coastal integrity. Furthermore, the elevated water levels contribute to the surge in sea levels, thereby amplifying the risk of flooding in these already precarious urban areas. It is imperative that urban planning and infrastructure development consider these amplified risks. By incorporating green infrastructure and enhancing the permeability of urban surfaces, some of these effects can be mitigated, thereby reducing runoff and promoting natural water absorption.

Furthermore, the socio-economic implications of these climatic interactions are profound. In urban settings, vulnerable populations often inhabit areas more prone to flooding and erosion, and they often lack the resources to implement effective responses. This underscores the necessity for targeted interventions that address both the infrastructural and social aspects of climate resilience. Policies should aim to foster equitable resource distribution and ensure that all community segments, particularly the most vulnerable, have access to protective measures against the consequences of SLR and CE.

Intensifying Weather Patterns: The rise of extreme weather patterns is only exacerbating the aforementioned issues. The increase in storm fronts and extreme coastal weather conditions accentuate the rate at which coastlines erode and the tidal damage caused. As many different localized variables contribute to climate issues, the warming of our planet is affecting weather on a global scale, causing a compound of unique climate interactions. A study focusing on the rise in extreme weather events found:

> Such evidence includes the observed increase in annual precipitation amounts, particularly in higher latitudes, regional increases in heavy precipitation amounts, and observed increases in atmospheric humidity in North America (Ross and Elliot 1996), China (Zhai and Eskridge 1997), and soil moisture in the former Soviet Union (Georgievsky et al. 1998). Trenberth (1999) proposes a conceptual model showing the effect of increased greenhouse gases on the hydrologic cycle and other factors affecting many climate extremes. Within this model, increased radiative forcing increases surface heating and latent heating, resulting in both increased air temperature and evaporation. This would lead to increased atmospheric water vapor content, increased precipitation rates, and enhanced storm intensity. (Easterling, et al. 2000, 423)

As the weather grows warmer, so does the occurrence and intensity of extreme weather cycles. A study in hurricane intensity and frequency using various algorithms to account for different input variables also found increases in extreme weather type frequencies in 16 out of the 18 Hydrologic Unit Code 2 region watersheds:

> The highest frequency increases exceeding 100% are found for the California, Texas Gulf, and Souris Red Rainy watersheds. These frequency increases resemble patterns in observed extreme precipitation increases (Reidmiller et al., 2017), indicating that changing large-scale dynamics were important in observed extreme precipitation trends over the CONUS (e.g., Huang et al., 2018). (Prein 2021, Mearns 2021, 16)

As the earth warms. we can expect the number of hydrological events to increase as more moisture enters the earth’s closed system, altering weather cycles to shift to extremes on different ends of climate spectrums and a rise in the need to account for the intensity in future weather events will increase. The intensity and frequency of these events will only further or exceed predictions of climate impact models in conjunction with the activities already in place due to anthropogenic influences. More extreme weather cycles ultimately accelerate climate events such as coastal erosion and rising sea levels.

In conjunction with the previously stated climate factors, understanding natural phenomena and the variable impact of human activities must be accounted for when analyzing climate activity to understand the broader sense of climate intensity. In July 2023, the European Geoscience Union published a paper[1] focusing on the seeding of clouds within cargo shipping corridors. This phenomenon was spurred by the release of Sulphur dioxide resulting from fuel burning — a process that generates rain droplets containing Sulfuric Acid. In 2020, the UN's International Maritime Organization enacted a new regulation to control Sulphur Dioxide emissions within shipping lanes. Unexpectedly, this regulatory change had a ripple effect, indirectly reducing cloud cover over Arctic shipping routes. Consequently, this reduction led to a significant increase in glacial melting. It necessitated adjustments to climate models and offered a sobering perspective on the acceleration of our climate crisis. Much of the newfound Arctic melting can be attributed to the increased sunlight reaching the ice sheets[2]. Many climate models only focus on the direct result of natural processes brought about by climate change. When adjusting regulations and introducing climate models, understanding the impact of human activities on climate events is crucial in understanding and forming complete climate models. The revelation of this climate correlation highlights a much more significant rate of climate degradation than originally conceived. With the rise of more intensive weather and increased warming of our global systems, so too will we see the rise of oceanic levels and coastal threats.

The intensification of weather patterns and the warming of our global systems lead to the inexorable rise of ocean levels and increasingly potent coastal threats. This escalatory cycle is

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[1] Diamond 2023

[2] Wood 2021

further compounded by human activities deeply interwoven with natural climatic processes. For instance, urban development along coastlines increases local economic activities and places more infrastructure and human lives at risk from rising sea levels and intensified storm surges. These developments, often driven by the allure of coastal amenities and economic opportunities, paradoxically contribute to the vulnerability of the regions they seek to benefit.

The construction of seawalls, levees, and other coastal defenses is a typical response to these threats. However, these solutions can sometimes have unintended consequences, such as habitat destruction for local wildlife and the disruption of natural coastal processes, which can further exacerbate the erosion they aim to prevent. Moreover, the economic burden of constructing and maintaining such defenses often falls disproportionately on local communities, many of which may lack the resources to implement long-term mitigation strategies effectively.

As urban planners and policymakers grapple with these challenges, the role of environmental justice becomes ever more critical. It is crucial to note that lower-income communities and minority populations frequently inhabit areas most vulnerable to climate impacts due to historical and ongoing processes of marginalization. These communities often face the "triple jeopardy" of exposure to hazards, sensitivity due to socioeconomic factors, and limited capacity to respond to and recover from environmental disasters. The importance of acknowledging and addressing these disparities cannot be overstated. It is essential in crafting climate resilience strategies that are not only effective but also equitable.

Furthermore, the interplay between human-induced environmental changes and natural climatic cycles creates a complex web of feedback mechanisms that can accelerate the impacts of climate change. For example, deforestation for agricultural expansion or urban development leads to reduced carbon sequestration, exacerbating global warming and increasing the intensity of hydrological cycles. This feedback loop, in turn, can lead to more severe flooding and erosion, undermining the land uses that contributed to their intensification.

This intricate relationship underscores the necessity of integrating a larger understanding of human and natural activities in climate modeling and policymaking. Focusing solely on human-induced changes or natural climatic cycles is not enough. As we proceed to the next chapter on the history of sea level rise and coastal erosion, we must delve into how past interactions between human actions and natural processes have shaped current vulnerabilities and explore historical responses to these challenges. By examining these in historical contexts, we can better understand the trends that have led to our current predicament and potentially forecast future conditions, allowing for the development of more comprehensive and preemptive climate resilience strategies. This historical perspective will also provide a foundation for discussing the efficacy of past mitigation efforts and the lessons they offer for contemporary climate challenges.

To follow, to enhance our understanding of the intricate dynamics between human activities and natural climatic cycles, we must delve deeper into how human interventions have shifted natural processes, sometimes with severe consequences. For instance, seeding clouds through sulfur dioxide emissions from ships has had unintended impacts on global climate patterns, specifically by altering precipitation and accelerating ice melt in vulnerable regions like the Arctic. This human-induced modification of natural systems underscores the complex interactions that can exacerbate the effects of climate change and heighten risks associated with sea level rise and coastal erosion.

The impact of human activities on climate is not limited to direct interventions like cloud seeding. Urbanization, a global phenomenon, has profound effects on local and global climates. Cities fundamentally alter local weather patterns with their vast stretches of impermeable surfaces and heat-absorbing materials. They contribute to the urban heat island effect and disrupt local hydrological cycles. This disruption can enhance the frequency and intensity of extreme weather events, including heavy rainfall that can lead to accelerated coastal erosion. The increase in impervious surfaces prevents natural water absorption by the soil, leading to greater runoff and increased pressure on urban drainage systems, often resulting in enhanced flood risks. The global trend of increasing temperatures further magnifies these urban effects on climate. The rise in global temperatures, driven by human activities such as deforestation and burning fossil fuels, contributes to the melting of polar ice caps and glaciers, leading to rising sea levels. This sequence of events threatens coastal communities with more frequent and severe flooding, particularly during storm surges. The complexity of these interactions demands that climate models incorporate the direct impacts of urbanization and industrial activities and the secondary effects these may have on global climate systems.

Adapting to these challenges requires more than traditional engineering solutions. It calls for innovative strategies that address the underlying causes of increased vulnerability, such as social inequality and ecological degradation. Effective adaptation strategies must, therefore, include efforts to restore natural landscapes that can act as buffers against floods and storms, such as mangroves and wetlands, and reverse the effects of climate change. These landscapes also provide habitats for wildlife and help maintain ecological balance. By fostering community resilience through inclusive and equitable approaches, it is possible to enhance the adaptive capacity of urban areas to withstand and bounce back from the effects of sea level rise and coastal erosion.

As this discussion transitions into the historical context of sea level rise and coastal erosion, it becomes essential to reflect on how past human-nature interactions have shaped the present landscape and what lessons can be drawn to mitigate future risks. Understanding the historical trends in human impact on climate and coastal environments will provide valuable insights into the cyclical nature of these challenges and inform more sustainable approaches to urban development and environmental management. This historical analysis sheds light on the effectiveness of past mitigation efforts.

Chapter II: Historical Perspectives & Human Interactions

In the Beginning: The history of sea level rise and coastal erosion in New York offers an interesting glimpse into the interplay between natural processes and human activities. Drawing from Betsy McCully's "City at the Water's Edge" and Robert E. Henshaw's "Environmental History of the Hudson River," we can analyze how these phenomena have shaped New York's coastline over millennia. This chapter will provide historical perspectives from New York to Charleston, from the past to the present, primarily focusing on New York’s relationship with SLR.

McCully[3] sheds light on the history of human interaction with the coastal environment. This interaction includes developing urban areas near shorelines and modifying natural waterways, exemplifying how human activities have accelerated coastal erosion, mainly by constructing infrastructure such as jetties and seawalls, which often disrupt natural sediment transport processes. Henshaw's "Environmental History of the Hudson River[4]" underpins the human impact by detailing the historical development along the Hudson River and its impact on nearby coastal areas, such as the development of Coney Island and the Lower New York Bay area, where natural shorelines have been significantly altered due to urban development and recreational use. The construction of coastal defenses, land reclamation, and dredging activities significantly alter natural erosion and deposition patterns, creating many variables affecting coastal areas. Henshaw's examination of the Hudson River also provides insight into how upstream activities can influence coastal dynamics, explaining how deforestation, industrial waste, and river traffic have impacted sediment flows into the estuary, subsequently affecting coastal erosion and rising sea levels in New York.

However, SLR and CE also pose a threat to our understanding of the past. The history of sea level rise and coastal erosion in New York provides a compelling glimpse into the interplay between natural processes and human activities. As we delve deeper into this historical context, it is evident that human settlements along New York's prehistoric coastlines were not only shaped by but also significantly influenced by the surrounding marine environment. This intricate relationship is highlighted by Amy E. Gusick and Michael K. Faught, who noted, "Awareness of

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[3] McCully 2007

[4] Henshaw 2011

and interest in the role that coastlines and coastal adaptations played in the development and dispersal of anatomically modern humans have grown over the last few decades" (Gusick and Faught 2020). This statement underlines the evolving recognition of coastal environments' importance to human development and survival.

Underlining the dynamic interplay between humans and their coastal environment, Gusick and Faught discuss the challenges presented by the submersion of archaeological sites: "While factors affecting the visibility of coastal sites have a global impact on archaeological research, the submersion of North American coastlines due to eustatic sea level rise presents a particularly significant obstacle in clarifying New World archaeological migration models and chronologies" (Gusick and Faught 2020). This challenge underscores the issues that rising sea levels pose to understanding our past and how these changes have obscured vital information regarding early human interactions with the coast.

The integration of coastal resources into daily life and survival strategies is a theme that recurred throughout prehistoric human history. As coastal areas provided rich resources, early inhabitants developed sophisticated adaptations to maximize these benefits, influencing their cultural and social development. The reliance on and adaptation to coastal environments can be seen in the extensive use of marine resources, landscape modifications, and even the strategic placement of settlements to exploit marine and terrestrial resources. The pursuit to uncover and understand these submerged sites has led to significant advances in archaeological methods. Gusick and Faught describe the proactive approach researchers took: "Today, the increased need to identify coastal adaptations and other early sites in submerged contexts in the New World has led researchers to obtain additional data from submerged continental shelf settings" (Gusick and

Faught 2020). This exploration enriches our understanding of past human behaviors and underscores the importance of these ancient coastal sites in constructing comprehensive models of human history.

These insights reveal that the narrative of sea level rise and coastal erosion is intricately woven with the story of human ingenuity and adaptability. Understanding the historical interactions between humans and their coastal environments in areas like New York and other metropolitan areas offers crucial lessons for contemporary coastal management and conservation efforts. It underscores the necessity of integrating historical data into current strategies, ensuring they are effective, sustainable, and informed by a deep understanding of the natural and human forces that have shaped our coastal landscapes over millennia.

From Past to Present: The Chapter "The Teeming Shore" by McCully[5] provides an in-depth look at the natural history of New York's coastal areas during the 1600's. It describes the diverse ecosystems found along the shores and delves into the region's geological history. Detailing the formation of barrier beaches and estuaries is key to understanding the area's susceptibility to sea level rise and erosion. Since the inhabitation and rise of settlements along the U.S. eastern seaboard, how we have handled sea level rise and erosion has varied. Colonists and early native settlers would strategically choose settlements along specific land areas near coastlines for increased protection from natural elements and access to natural resources.

Before examining the specific case of Charleston in the 1800s and 1900s, it is essential to acknowledge the broader historical context of coastal cities like New York City facing rising sea

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[5] McCully 2007

levels. Historical data, reconstructed through advanced scientific methodologies, indicates a notable increase in sea levels over the centuries, impacting urban landscapes across the Atlantic coast. These reconstructions are not mere statistical representations; they tell the story of how communities have historically navigated the relentless rise of the ocean—a challenge that still demands increasingly complex responses from urban planners and environmental scientists. The reconstructed trends of sea-level indicators, as mentioned by Kemp et al. (2017), were "established by radiocarbon dating and a Bayesian hierarchical model to accommodate age-proxies and provide a unified statistical framework for quantifying uncertainty," illustrating the precision and complexity involved in understanding past sea level changes.

The study by Kemp and colleagues underscores a significant turning point in the early 19th century when sea levels along the New York coastline began to rise at an accelerated pace. This period coincides with the onset of industrialization, a human activity that significantly contributed to increased greenhouse gas emissions and subsequent global warming—a key driver of sea level rise. The intricate reconstruction of these trends using radiocarbon dating and Bayesian models offers a clearer picture of how past human activities have amplified natural environmental changes. Kemp et al. (2017) further note that "The rate of RSL [relative sea level] increase marked notably between 1812-1913 from ~1.0 to ~2.5 mm/yr, which coincides with other reconstructions along the US Atlantic Coast." This scientific endeavor not only provides insight but also a crucial data foundation for predicting future trends and preparing for them with more targeted, resilient infrastructure solutions.

The historical rise in sea levels has necessitated evolving responses from coastal cities. In New York, like Charleston, the growing impact of sea levels has led to significant urban planning and infrastructural adaptations to mitigate flooding and erosion risks. As Kemp and colleagues note, the rate of sea level rise significantly increased in the early 20th century, underscoring the need for heightened coastal defenses. These adaptations have been crucial in managing the immediate effects of rising sea levels. However, they also highlight the ongoing need for innovation in coastal defense technologies and strategies, a testament to the dynamic nature of the challenge.

Furthermore, the scientific analysis reveals that the sea level rise has increased, and future changes in tidal ranges could further complicate the impacts. Such insights underscore the challenges coastal cities face and highlight the importance of integrating historical data into current urban planning and environmental management strategies. This forward-looking approach is critical as it allows city planners and policymakers to anticipate future conditions based on past trends, thus crafting more effective and sustainable responses to rising sea levels.

This historical perspective on sea level rise enriches our understanding of the past and serves as a critical foundation for addressing current and future coastal vulnerabilities. Cities like Charleston and New York have historically navigated these challenges, and their experiences provide valuable lessons on the necessity of adaptive strategies in coastal management. Reflecting on these historical adaptations and the continuous need for innovation offers vital insights into how best to balance the preservation of urban waterfronts with the relentless dynamics of nature.

During the 1800-1900's, as populations grew and communities expanded, more aggressive measures were sometimes required to protect valuable waterfront land and burgeoning urban centers. A prime example of this evolution in coastal defense and response was initiated by the people of Charleston, South Carolina. By the 1800s, Charleston, due to its low-lying position, faced persistent challenges from tidal flooding, exacerbated by periodic hurricanes. As a response, the city constructed a seawall (known as the "battery") to hold back the encroaching sea. This seawall became essential to Charleston's urban landscape, representing an early example of infrastructural solutions to coastal challenges. The seawall not only served to protect valuable property from flooding but also shaped the city's coastline, giving Charleston its unique waterfront character.

While the wall mitigated some of the immediate threats from the tides, it also highlighted the need for continuously evolving solutions in the face of changing environmental conditions. Charleston continued addressing these effects in the 1980s, as shown by the book "Effects of Changes in Stratospheric Ozone and Global Climate: Sea Level Rise":

> The peninsula is the portion of the Charleston area least vulnerable to sea level rise. It is currently protected by the Battery at the southern end, and Its port facilities provide stabilization. While the peninsula has various low-lying areas threatened by - Inundation and erosion, its high development density will likely make the protection of the areas economically justified. Sullivans Island, on the other hand, is a low-lying barrier island of highly erodible materials. Exposed to open-ocean wave attacks, it is extremely vulnerable to sea level rise. The low- to medium-density development on the island may be insufficient to make protection with a sea wall economical. Additionally, the substantial recreational value of its beaches would be lost if a sea wall were built. (Titus 1986, 60)

In the 1960s, as the U.S. recognized the ever-increasing challenges posed by rising sea levels and coastal vulnerabilities, another ambitious project was undertaken in the form of the Chesapeake Bay Bridge Tunnel. (CCBT) Spanning 17.6 miles and connecting the Delmarva Peninsula's Eastern Shore of Virginia with Virginia Beach and the metropolitan area of Hampton Roads, Virginia, the bridge tunnel became a marvel of modern engineering. Several factors led to the bridge tunnel's construction. For one, the previous ferry system needed to be improved to handle the growing traffic demands of the region. A more efficient and faster route was needed to bolster commerce, tourism, and regional connectivity. Additionally, military concerns played a role; the U.S. Navy wanted a more reliable and swift mode of transportation that did not interfere with the operations of the world's most extensive naval base in Norfolk, Virginia. Design considerations for the Chesapeake Bay Bridge Tunnel had to account for multiple challenges. Given its expansive length, the design needed to consider the varying depths of the bay, the powerful currents, and the potential for solid storm surges. To this end, the combination of bridges and tunnels was chosen. While bridges provided the elevation necessary to counteract potential flooding and rising sea levels, the tunnels allowed for unobstructed naval operations in the bay. The strategic placement of the tunnels at Thimble Shoal and Chesapeake navigation channels ensured that maritime traffic remained unaffected.

By the 1970s and 1980s, the federal government of the United States had become increasingly more aware of the vulnerabilities of coastal regions, prompting significant initiatives aimed at their management and protection. The Coastal Zone Management Act (CZMA) of 1972 became a cornerstone of these efforts. This act, driven by recognizing the importance of the nation's coastal areas, sought to "preserve, protect, develop, and, where possible, to restore or enhance the resources of the nation's coastal zone." (Government of the United States) The CZMA provided grants to states to develop and implement coastal management programs. It has encouraged states to take a comprehensive approach to coastal resource management, emphasizing the balancing act between development and conservation.

Another significant federal initiative of this period was the National Flood Insurance Program (NFIP)[6], introduced in 1968. The NFIP's main aim was to reduce the impact of flooding on private and public structures by providing property owners with an insurance alternative to disaster assistance. One of the program's pivotal elements was delineating flood zones and creating Flood Insurance Rate Maps (FIRMs) to guide development. By offering insurance only to those communities that adopted and enforced floodplain management regulations, the NFIP sought to curtail risky development in flood-prone coastal areas. The effects of this program have been multifaceted. While it has successfully promoted awareness about flood risks and fostered some community-level changes in development practices, it has also been criticized for inadvertently encouraging buildings in hazardous zones by offering below-market insurance rates. The CZMA and NFIP underscore the federal government's evolving role in addressing the challenges of coastal development, sea-level rise, and increased flood risk.

Modern Initiatives: The turn of the 21st century brought new challenges for coastal cities globally, and New York City was no exception. The megacity faced a harsh wake-up call in 2012 when Hurricane Sandy hit. Often called the "Superstorm," Sandy wreaked havoc across the Eastern Seaboard, with New York City suffering extensive damages and infrastructure failures. The storm surge led to unprecedented flooding, submerging many neighborhoods, causing widespread power outages, and damaging the city's vital transportation systems. This disaster

[6] Michel-Kerjan, Erwann O. 2010

catalyzed the city's administration to re-evaluate its resilience measures against rising sea levels and extreme weather events.[7]

In response, several protective and restorative projects were conceived and implemented. Among the most ambitious was "The Big U," a 10-mile protective system designed to shield Lower Manhattan from future flood events. Conceived by the Bjarke Ingels Group (BIG) and partners, "The Big U" integrates a series of levees, deployable walls, and landscaped berms that double as public spaces. These infrastructures were meticulously designed to protect the city from rising sea levels and storm surges and enhance the urban realm, providing recreational and social benefits to its residents. This multi-benefit approach showcases how modern cities blend infrastructure with urban design to tackle climate challenges while improving the quality of life (BIG - Bjarke Ingels Group). New York City's post-Sandy efforts exemplify the imperative for coastal cities to continuously innovate and mitigate in an era marked by the increasing unpredictability of climate impacts.

Managed retreat, a strategy often deemed a last resort, has increasingly entered discussions as some regions confront the reality that certain vulnerable coastal areas may not be defensible in the long term. This approach involves proactively moving assets and populations out of high-risk areas to reduce human and economic losses from sea level rise and extreme weather events. Beyond just reactive measures post-disaster, the managed retreat[8] has started to be considered a planned and strategic policy for vulnerable areas.

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[7] Rosenzweig, Cynthia, and William Solecki 2014

[8] Hino, M., Field, C. & Mach, K. 2017

Some state governments have undertaken notable efforts in this domain in recent years. For instance, in New Jersey, the state's Blue Acres Buyout Program, initiated after Hurricane Sandy, focuses on buying homes from willing sellers in flood-prone areas. Once these properties are acquired, the structures are demolished and the land is permanently preserved as open space, serving as a natural buffer against future flooding and storm surges. This approach to sea level rise reduces the risk to human life and property. It allows these areas to revert to their natural state, providing ecological benefits and acting as a sponge to absorb floodwaters. The program signifies a shift in thinking — from an era of resistance against the forces of nature to one of coexistence, where the environment's natural defenses are harnessed to protect communities. As sea levels continue to rise and the impacts of climate change become more pronounced as global temperatures rise, such strategies underscore the need for a balance between protective infrastructure and the acceptance of nature's limits.

Chapter III: The Economics of it All

The Economy Surrounding SLR and Adaptive Means: In addressing the problem of sea level rise and coastal erosion, we have presented the main issue at hand and the worsening conditions contributing to the aggregate of problems afflicting NYC; in addition, we have touched upon the historical perspectives and responses to sea level and coastal encroachment. Most policies and initiatives in place reserve an adaptive approach, as mentioned before, to address climate change issues. This chapter will critique the economic effects climate adaptation projects undertake and require, primarily focusing on gray adaptation measures currently proposed. Note that the main argument proposed against adaptive climate response is that they take on diminishing returns economically. As a problem is addressed and adapted, the upkeep for ever more intensifying climate variables also rises. Therefore, more investment must be funneled into the upkeep of the climate response to continue operating as intended. While this may be a consequence of inadequate climate planning, a revitalization in how we plan climate action is needed to retain the economic sustainability of a massive undertaking such as climate response. Especially as climate variables become more extreme, introducing measures that can meet the demand and fluidity of climate extremes is necessary.

Adaptive options:

Climate adaptations break down into three categories[9]: Green (green infrastructures and natural barriers such as coral reefs, mangroves, and wetlands), Gray (dikes, pump stations, elevated roads, bridges, levees, and gates, and storm surge barriers), and Pink (policies, land use allocations, education, and social involvement). Green adaptation is one of the most effective means of climate change mitigation. However, it is highly abstract in its application, requiring careful planning to ensure effective adaptation, with pink being dependent on the population's social initiative to measure the lengths and guidelines of climate adaptation. Gray is the most widely used application of climate change response in its relatively straightforward approach.

Economic Expectations:

Adaptive measures will employ one or multiple of the above initiatives to address climate issues (explicitly relating to SLR); while effective briefly, most in-place initiatives will fall short of intended targets due to the variability of climate events. Underpinning this problem is the project proposal of a six-mile sea wall to protect NYC from SLR. The proposal estimates the cost of implementing such a measure to be around 119 billion dollars, with outlooks of a growing

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[9] Nazarnia, Hadi & Nazarnia, Mohammad & Sarmasti, Hadi & Wills, W.. (2020). A Systematic Review of Civil and Environmental Infrastructures for Coastal Adaptation to Sea Level Rise. Civil Engineering Journal. 6. 1375-1399. 10.28991/cej-2020-03091555.

number to be expected; in addition, 35% (or 41.7 billion dollars)[10] of that cost would be paid for by New York and New Jersey residents.

Furthermore, once in place, maintenance of the wall would have to be a continuous area of expense to maintain its efficiency. Maintenance of levees similar in scope in New Orleans[11] was projected to be a minimum of 14 billion dollars in upgrade costs to meet climate needs. It is important to note that once the infrastructure is in place, it can only adapt to future climate cycles via being supplemented by more investment. This sentiment has been felt in other climate projects in addition to this one in a letter from the city comptroller:

Venice's MOSE barriers have been in construction since 2003, and since the start of construction, escalating estimates of sea level rises have put into question whether the barriers will be able to match the challenges of sea rise. The feasibility report offers relatively little information about how the barriers will operate and under what thresholds the barriers will rise. Though the Corps suggests the barriers will only be deployed for serious storms, rising sea levels are expected to amplify the flooding risks posed by smaller and smaller weather events. (Cite:City Planer Letter). Besides its economical draining of funds better appropriated elsewhere, this mega project would drastically alter the Manhattan ecosystem, leaving large swathes of Manhattan Bay walled off, stagnant, and environmentally unfit for most native organisms. (Stringer 2019, 3)

To make projects like these work, continued investment in maintenance and upgrades are required to keep the functionality of projects like these in place. Maintenance of eroding infrastructure, adapting to other compounding variables from the implementation of the sea wall, and a myriad of other variables will add to the sunk cost of building a sea wall without exploring alternatives and hybrid means of adaptation or outright mitigation in conjunction.

Climate change adaptation, especially in urban areas, necessitates substantial financial investment. As "The financial burden of urban infrastructure resilience is substantial, with

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[10] The Government of the United States, 2022

11 Thomas Frank, E&E News. 2019

estimated annual costs ranging up to US$52 billion by 2050 if current urban planning and climate adaptation strategies remain unchanged." (Causevic et al. 2021). This significant figure reflects the urgency and scale of interventions required to mitigate the impacts of sea-level rise and urban flooding. It underscores the need for a strategic approach to financing that covers initial setup costs and ensures sustainable funding for ongoing maintenance and upgrades.

Moreover, the economic toll of adapting urban infrastructure to climate change is unevenly distributed, often placing a disproportionate strain on developing regions. According to Causevic et al. (2021), "Financial constraints are particularly acute in developing countries where urban areas are predominantly vulnerable. These regions face a stark discrepancy between the needed investment for flood resilience and the available financial resources." This disparity highlights the need for innovative financial mechanisms to bridge the funding gap, ensuring that vulnerable communities can implement necessary adaptations without compromising economic stability. In addition to the financial burden, urban climate change adaptation faces other challenges. Political will and effective governance structures are crucial for successfully implementing adaptation measures.

Political considerations can sometimes impede progress, especially when short-term economic interests are prioritized over long-term climate resilience. Therefore, engaging stakeholders and decision-makers early in the process is essential to ensure buy-in and support for adaptation initiatives. This support can include collaborating with local governments, community groups, and businesses to build partnerships that promote shared responsibility and investment in urban climate resilience.

One of the primary challenges is to ensure that adaptation measures are not only effective but also equitable and inclusive, particularly for marginalized communities. The effects of climate change are not uniformly distributed, and vulnerable populations such as low-income households, communities of color, and indigenous peoples often face disproportionate risks and barriers to adaptation. Therefore, it is of utmost importance to incorporate a social justice perspective into adaptation planning by assessing the differential impacts of climate change on various groups and devising strategies that prioritize the needs of the most vulnerable. This can involve providing targeted financial and technical assistance to marginalized communities, fostering community-led decision-making, and ensuring that adaptation measures do not exacerbate existing inequalities.

Breaking Down Adaptive Outcomes and Economic Expectations: The economic implications of adaptive climate measures extend beyond the initial investment. The maintenance and upgrading of these structures entail ongoing financial commitments, which can balloon over time as the impacts of climate change intensify. This continuous outlay can become a fiscal burden, particularly for cities facing multiple climate threats that require varied adaptation strategies. Additionally, the focus on gray infrastructure often overshadows investments in green and pink adaptations, which, though initially less tangible in their economic benefits, can offer more sustainable and cost-effective solutions in the long term. On top of less tangible economic benefits, their employment is restricted by area and can be highly variable in the design approach due to social sentiment and employability.

The cost dynamics of climate adaptation further complicate fiscal planning. As Causevic et al. (2021) note, "The cost of inaction is often much higher than the costs associated with implementing resilience strategies. However, the initial investments required can be formidable, posing significant challenges for budget-constrained municipalities." This observation points to the critical balance between the immediate financial burdens of adaptation measures and the long-term savings they offer by mitigating future damages.

In addition, the financial challenges extend to the scope of funding required for comprehensive adaptation strategies. "Adaptation measures, while crucial, face financial hurdles that can limit their implementation. The gap between the cost of necessary adaptations and the funding available can result in delayed or inadequate responses to climate threats," according to Causevic et al. (2021). This statement underscores the importance of securing adequate and timely funding to implement effective adaptation measures to keep pace with climate change impacts' rapid evolution.

It is not only the funding gap that poses challenges to implementing effective climate adaptation measures. The complexity and uncertainty of the climate system itself make it difficult to identify and prioritize adaptation strategies. As noted by the National Research Council (NRC) in their report on America's Climate Choices, "The complexity of climate change and its interactions with other environmental and social factors can create significant uncertainties and challenges for decision-making."(National Research Council, 2011) This complexity is compounded by the fact that climate change impacts are not evenly distributed and vary by region, sector, and community. Thus, adaptation measures must be tailored to local contexts and vulnerabilities, further complicating the task of identifying effective strategies.

Climate adaptation is not just a matter of physical infrastructure and engineering solutions. It requires a holistic approach that integrates social, economic, and governance aspects. As highlighted by the Intergovernmental Panel on Climate Change (IPCC), "Adaptation is a process that involves actors at multiple scales, from individuals and households to governments and international organizations, and that requires changes in behavior, institutions, and policies."(Intergovernmental Panel on Climate Change, 2014) This means that effective climate adaptation requires not only technical solutions but also social innovation and institutional transformation. It requires a fundamental shift in the way we think about and approach development and governance, moving away from a business-as-usual mindset to a transformative agenda that prioritizes sustainability, equity, and resilience.

Infrastructure built today may need to be improved to handle the more severe weather patterns and sea-level rises predicted for the future, leading to potentially wasted investments and the need for further spending on upgrades or new projects. This aspect of uncertainty in climate predictions adds a layer of financial risk to the already hefty investments. Breaking down these measures, we can begin to see how they stack up economically against one another:

Green Adaptation Measures: The role of green infrastructure is becoming increasingly significant. Elements such as parks, green roofs, and urban forests offer an effective solution for flood mitigation and heat reduction but also provide long-term economic benefits. These include improved air quality, increased biodiversity, and enhanced urban livability. An example of such investment is the East River Park project. With its comprehensive green infrastructure, this project is estimated to cost around $1.45 billion, a figure that encapsulates its construction expenses and long-term environmental benefits, whose long-term investments pale in comparison to the six-mile sea wall but lack immediate results and remain localized to designated areas.

Gray Adaptation Measures: Demand a significant upfront investment along with ongoing maintenance. A striking example is the proposed six-mile sea wall designed to protect NYC from rising sea levels. This project is estimated to cost a staggering $119 billion, a testament to the substantial financial commitment gray infrastructure entails. This figure does not stand alone, as annual maintenance and upgrades, such as those akin to the New Orleans levee system (which demands billions in upkeep), add to the total expenditure.

Pink Adaptation Measures: Due to often being couched as less economically tangible, policies and community involvement can be delicate to navigate, having the potential to become the backbone of successful climate adaptation or the red tape that heavily halts climate progression. These Pink measures, encompassing education, zoning laws, and land use policies, can potentially lead to significant cost savings. By preventing. construction in high-risk areas and promoting sustainable practices, they reduce the need for expensive physical infrastructure. However, the cost-effectiveness of these measures largely hinges on the level of community engagement and the efficacy of policy enforcement.

Future Estimates of Climate Costs: Rising Costs Due to Increasing Climate Events: With the intensification of climate change, a corresponding increase in the frequency and severity of extreme weather events is anticipated. This escalation will undoubtedly lead to heightened costs for adaptation and recovery. A study[12] conducted by the Center for Climate Integrity projects that by 2040, sea level rise alone could impose over $100 billion in coastal defense expenditures on New York State.

[12] Leichenko, Robin, David Major, Katie Johnson, Lesley Patrick, and Megan O'grady 2023.

Comprehensive studies are needed to compare the long-term economic benefits of varying adaptation strategies. While Gray infrastructure offers immediate protection, its associated high maintenance costs and limited adaptability may make it less economically viable in the long run, especially compared to hybrid solutions. Notably, the economic repercussions of inaction are projected to be significantly higher in the long term than the costs of proactive measures upfront. The Environmental Defense Fund reports that the economic losses resulting from climate-induced coastal flooding could soar into the trillions by the century's end, should adequate adaptation measures not be implemented.

Economical Introduction on What it Means to Mitigate:

The fiduciary implications of adaptive climate approaches highlight the high expenditure already in circulation regarding solutions. For a system to be sustainable, it must operate in a closed economy and be self-sufficient and propagative. To effectively combat and reduce climate change, solutions must forecast future climate expectations in the worst-case scenario to prepare for the long-term survivability of climate initiatives. This approach contrasts with adapting solutions to scenarios as they impose more of a heavy influence on our daily functions. Sea walls were proposed not until after Hurricane Sandy, while data on the intensification of storm cycles has been available since at least the 1980s. To address climate issues more effectively than before, mitigative solutions must operate and incorporate green, gray, and pink initiatives while employing an economically sustainable framework following cradle-to-cradle, closed-loop operations and be circular both in application and economics. In addition, solutions must also comprehend, to the best of their capabilities, the long-term implications of climate change in a localized area and forecast solutions that do not rely on sustained investment but operate on creating profit areas. Mitigative initiatives are expanded in Chapter 5 but highlight the opportunity to turn climate costs into profit areas if addressed correctly. The economy surrounding climate response is complex and expensive, though if handled genuinely sustainably, it offers the most cost-effective and potentially lucrative benefits of any other mover of economics.

Amidst the ongoing debate on climate adaptation, the discourse is now gravitating towards the practical implications and the costs entailed in implementing and sustaining these initiatives. The reliance on gray infrastructure, exemplified by the proposed six-mile sea wall encircling New York City, underscores a conventional approach aimed at immediate risk mitigation. However, the financial ramifications are staggering, with construction costs alone projected at $119 billion, in addition to substantial annual maintenance expenses. This underscores a crucial facet of climate adaptation strategies—the necessity for continuous financial resources that could potentially strain local economies over time.

The economic sustainability of such large-scale projects could be better, particularly when considering the diminishing returns associated with infrastructure that must be continually upgraded to cope with escalating climate threats. This problem necessitates a broader evaluation of alternative and hybrid adaptation strategies that integrate green and pink measures, which could offer more sustainable and cost-effective solutions in the long run. For instance, while offering long-term environmental and economic benefits such as improved air quality and enhanced urban livability, green infrastructure often needs more immediate impact than tangible gray infrastructure projects.

Transitioning from the economics of adaptation to the political and policy dimensions, it is clear that climate change adaptation transcends mere technical challenges and enters the realm of governance and public policy. Effective adaptation strategies require robust political support and governance frameworks that can facilitate the implementation of comprehensive measures. Political will is often tested amid urgent economic pressures and competing interests, where long-term sustainability may be sacrificed for short-term gains.

The need for an integrated approach becomes even more critical when considering the uneven impacts of climate change across different regions and communities. In developing countries or marginalized communities within more developed nations, vulnerable populations often face disproportionately high risks and barriers to effective adaptation. This inequality calls for policies that address the technical aspects of adaptation and ensure that these measures are equitable and inclusive. Ensuring that adaptation strategies are culturally sensitive and aligned with the needs of these communities is crucial for their success, as well as translating their effectiveness domestically in urban centers like NYC.

Adaptation policies must be agile and capable of adapting to the evolving climate and the emerging science surrounding it. This necessitates a governance structure that can react promptly and effectively to new information and changing circumstances, fostering resilience in infrastructure and the social and economic systems that support human communities.

As we transition into a detailed exploration of the political and policy challenges in Chapter 4, the focus will be on unraveling the intricacies of implementing climate adaptation policies. The discussion will delve into the interplay between local and national governance, the roles of various stakeholders including governments, private sectors, and civil society, and the international dimensions of climate policy. Grasping these dynamics is pivotal to formulating policies that are not only effective in mitigating the impacts of climate change but are also politically feasible and socially just.

This exploration will also examine the potential for policy innovation to enhance the effectiveness of adaptation strategies in more mitigative measures. Innovative financing mechanisms could be crucial in bridging the funding gaps that hinder effective adaptation, particularly in resource-constrained settings. Additionally, the chapter will explore how policy frameworks can be designed to encourage the integration of green and pink adaptation measures, which may offer more sustainable alternatives to traditional gray infrastructure.

While the technical and economic aspects of climate adaptation are critical, the success of these efforts ultimately hinges on the political and policy frameworks in place. As we transition into the next chapter, we will emphasize understanding these frameworks and how they can either facilitate or hinder effective and equitable climate adaptation.

Chapter IV: Policy and Action

The Importance of Policy: In addition to the adaptive initiatives in Chapter Three, local policy and organizations also play a crucial and complex role in addressing climate change and its influence. This chapter is dedicated to raising awareness around some policies and organizations influencing the fight against climate change. Most of these initiatives are in response to current climate change; however, some are starting to tackle the future of climate change using natural-based solutions. The dynamic solutions offered in policy and organization offer more nuanced approaches to specific aspects of climate change. This flexibility allows initiatives to be adjusted or phased out depending on their application.

Expanding the role of local policies and organizations is crucial to acknowledging the dynamic landscape of urban adaptation strategies. Climate change has become a major challenge in urban areas, and cities have become the front line in the battle against climate change. As cities are responsible for more than 70% of global greenhouse gas emissions, they are also the places where the impacts of climate change are most keenly felt. The urgent need for cities to adapt to climate change has led to a growing awareness of the importance of local adaptation strategies. Local policies and organizations play a crucial role in developing and implementing these strategies. They are often better placed to understand the specific challenges faced by their communities and can tailor their responses accordingly. This initiative is significant in developing countries, where cities often need more resources and expertise to develop adaptation strategies.

Gornitz et al. (2020) noted that "The resiliency initiatives not only reflect a growing awareness of the severe implications of climate change but also a shifting paradigm in urban policy, where the focus is moving from mere mitigation to robust adaptation strategies." This perspective highlights the need for policy frameworks to anticipate and react to the multifaceted challenges of climate change. The focus on resilience recognizes that climate change is a complex and dynamic phenomenon that requires a multifaceted response. Such an approach requires various strategies addressing the physical, social, and economic dimensions of climate change. This awareness requires a shift away from traditional approaches to urban planning that focus solely on physical infrastructure. Instead, cities must adopt an integrated approach combining physical infrastructure with social and economic policies.

The case of New York City presents unique challenges and strategies in the context of climate change. New York City is one of the world's most densely populated and economically important cities. It is also highly vulnerable to the impacts of climate change, including sea-level rise, storm surge, and extreme weather events. The city's response to these challenges has adopted a multifaceted approach that emphasizes physical infrastructure and social and economic policies. This approach recognizes that climate change is not just an environmental challenge but also a social and economic one.

Oppenheimer et al. (2020) highlight this, stating that "Addressing the dual challenges of climate change and social equity, NYC's policies aim to create not just a resilient city, but an equitable one where all residents, regardless of their socio-economic status, are protected from the environmental stresses exacerbated by climate change." This commitment is crucial for ensuring climate resilience benefits all population sectors equally. To achieve this goal, the city has implemented a range of policies that address the physical infrastructure and social and economic factors. For example, the city has invested heavily in public transportation, reducing greenhouse gas emissions while providing affordable and accessible transportation for all residents. The city has also implemented policies to address social equity, such as affordable housing initiatives, community engagement programs, and job training programs.

The Evolution of NYC's Policy: New York City's climate policy has evolved significantly over the years. Initially, the city introduced PlaNYC 2030 in 2007, a plan to address the city's aging infrastructure and prepare for the challenges of climate change. However, this plan fell short of expectations due to a lack of true innovation, failed promises, and inadequate community outreach[13]. PlaNYC 2030 was created with the assistance of the New York City Panel on Climate Change (NPCC), modeled after the Intergovernmental Panel on Climate

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[13] Hilliker 2022

Change (IPCC) at the United Nations. This panel's significance grew significantly after Hurricane Sandy and the Trump Administration's withdrawal from the Paris Climate Accords [14].The plan, however, was criticized for being somewhat hypocritical, as it emphasized long overdue infrastructure improvements rather than introducing groundbreaking climate policies. The plan's limitations became more apparent with the city's water supply strain, mostly due to high residential usage. PlaNYC 2030[15] was eventually scrapped only seven to eight years into its intended 23-year lifespan for a more proactive approach.

This failure led to the introduction of OneNYC 2050 in 2015, which promised a decisive policy designed for climate change, reflecting values such as fair and equitable distribution of aid and an emphasis on green infrastructure. OneNYC 2050 aimed to address the failures of PlaNYC 2030, such as the lack of serious ambition and the shortcomings in social outreach. The plan was more exhaustive, covering a wider variety of subjects with organized initiatives, such as the 80 x 50 initiative, which aims to reduce emissions by 80% by 2050[16]. It was considered necessary to replace PlaNYC 2030 and respond to the federal administration's stance on climate change.

The urgency of integrating climate resilience into urban planning and infrastructure development is a key point raised by Horton et al. (2020). They argue, "The integration of climate resilience into urban planning and infrastructure development is no longer optional but a necessary paradigm to ensure the sustainability of our cities in the face of unpredictable climate risks." This statement calls for an integrated approach that combines infrastructure resilience with

[14] Hilliker 2022

[15] “NYC Mayor’s Office of Climate and Environmental Justice

[16] Hilliker 2022

proactive community planning. Such an approach recognizes that climate change is not just an environmental challenge but also a social and economic one.

To achieve this goal, cities must adopt an integrated approach combining physical infrastructure with social and economic policies. This requires a shift away from traditional approaches to urban planning that focus solely on physical infrastructure. Instead, cities must adopt an integrated approach combining physical infrastructure with social and economic policies. For example, cities can invest in green infrastructure, such as green roofs, rain gardens, and bioswales, which not only reduce the impacts of climate change but also provide other benefits, such as improved air quality, reduced stormwater runoff, and enhanced biodiversity. Cities can also implement policies to promote sustainable transportation, such as bike lanes, car-sharing programs, and public transportation systems.

NYC's Push Towards Policy: A large part of NYC's climate policy came to fruition through the combined efforts of grassroots activism and economic incentives. During a Protection Committee hearing on proposed legislation, Pete Sikora's statement highlighted the urgency of climate action in response to federal inaction during the Trump administration[17]. Sikora emphasized that with Trump in office, the legislation was crucial to meet the climate crisis challenge that the federal government failed to address at a critical moment. In addition, The People's Climate March in September 2014, which coincided with the publication of "One City Built to Last," is an example of grassroots activism's influence over climate policy. This event, occurring ahead of a UN climate summit in New York, brought 300,000 climate activists

[17] Swinburn, Boyd A, Vivica I Kraak, Steven Allender, Vincent J Atkins, Phillip I Baker, Jessica R Bogard, Hannah Brinsden, et al. 2019

to the city's streets and was labeled as the "biggest ever call to action on climate change." (Swinburn 2019, 823) Following this march, pressure from grassroots interest groups for greenhouse gas (GHG) mandates began to mount significantly. In 2015, a pivotal moment occurred when ALIGN, an alliance of labor and community groups, formed the Climate Works for All coalition[18]. This coalition called for mandatory energy use performance targets for buildings, viewing these targets as a way to address climate change while creating jobs in the city.

These past engagements with climate activism and failures in policy all helped pave the road and influence the current climate policy in place. These examples help highlight the multifaceted and complex origins of climate policy and remain as engagement frameworks in future climate initiatives.

The role of community engagement in shaping effective climate adaptation strategies cannot be overstated. Rosenzweig et al. (2020) highlight the effectiveness of community-based approaches: "Community-based adaptation strategies have demonstrated significant potential in not only addressing the impacts of climate change but also in empowering communities, thereby fostering a more inclusive approach to climate governance." Such strategies ensure that adaptation measures are not only practical but also equitable.

To achieve this goal, cities need to adopt a community-based approach involving all population sectors. This requires a shift away from traditional approaches to urban planning that

[18] Swinburn, Boyd A, Vivica I Kraak, Steven Allender, Vincent J Atkins, Phillip I Baker, Jessica R Bogard, Hannah Brinsden, et al. 2019

are top-down and technocratic. Instead, cities need to adopt a more participatory approach involving all sectors of the population, including marginalized communities, in planning and implementing adaptation strategies. This requires various strategies, such as community engagement programs, public education campaigns, and participatory decision-making processes. By involving all sectors of the population in planning and implementing adaptation strategies, cities can ensure that their responses are effective, equitable, and socially just.

Current Climate Policy: CCRA: One of the most widely recognized policies considering climate change is the Community Risk and Resiliency Act (CRRA)[19] enacted in 2014 to address the threat of rising sea levels in NYC. The CRRA requires state agencies to consider future physical climate risks, such as sea-level rise, storm surges, and flooding in certain permitting, funding, and regulatory decisions. This includes integrating climate change considerations into state projects, programs, and investments. In addition, the CCRA[20] is aimed at more transparent climate reporting, mandating the Department of Environmental Conservation (DEC) to adopt official sea-level rise projections and update them at least every five years. In conjunction with the Smart Growth Public Infrastructure Policy Act, the policy aims to ensure public investments in projects promoting intelligent, sustainable growth and which are less vulnerable to climate-related risks.

Smart Growth Public Infrastructure Policy Act:

[19] "Community Risk and Resiliency Act (CRRA)

[20] "Community Risk and Resiliency Act (CRRA

This policy promotes sustainable and efficient development in New York State. It encourages constructing and maintaining public infrastructure in an economically viable, environmentally responsible way that benefits community welfare. In the context of climate change, this policy becomes even more significant as it guides the development of resilient infrastructure to climate-related risks such as extreme weather events and rising sea levels. The policy aims to reduce the environmental footprint of public infrastructure projects, promote the efficient use of land, and support the development of vibrant, healthy communities[21].

The Open Space Conservation Plan:

This plan serves as a guide for New York State's land conservation efforts. It recognizes the critical role of open spaces like forests and wetlands in combating climate change. These ecosystems offer invaluable services, such as carbon sequestration, which helps reduce greenhouse gases and natural protection against flooding and storm surges. By conserving open spaces, the plan contributes to the state's broader climate action strategy, ensuring that these natural areas continue to provide ecological, economic, and social benefits[22].

The New York Ocean Action Plan:

This plan focuses on enhancing the resilience of ocean ecosystems in the face of climate change. It outlines a series of actions aimed at preserving the health and sustainability of ocean resources, which are increasingly threatened by changes in climate. These actions may include measures to protect marine habitats, mitigate the impacts of ocean acidification, and manage

[21] NYS Smart Growth Program. n.d. Department of State

[22] 2016 Open Space Conservation Plan - NYDEC

fisheries sustainably. The plan is crucial for safeguarding marine biodiversity and supporting the livelihoods and communities that depend on ocean resources.[23]

The Hudson River Estuary Action Agenda 2021-2025:

This agenda explicitly addresses the challenges communities face along the Hudson River due to the impacts of climate change. It acknowledges the increased risk of flooding from stronger storms and the threats posed by rising sea levels. The agenda sets out a series of actions and localized strategies to enhance the resilience of these communities, protect the river's ecosystem, and ensure sustainable use of the estuary's resources[24]. This policy involves flood risk management, habitat restoration, and promoting sustainable development along the river.

NYC's policy addressing future climate threats such as SLR and Coastline erosion offers a dynamic blueprint in the fight against climate change. Using hybrid approaches aimed at both public initiatives and direct ecosystem rehabilitation allows for a more nuanced understanding of what facilitates the most effective climate strategy. Ensuring the effectiveness of these policies also requires robust governance frameworks that promote transparency and inclusiveness. Orton et al. (2020) stress the importance of inclusive policy-making: "Effective climate adaptation requires transparent governance where stakeholders, including marginalized communities, have a say in the policies that directly impact their lives." This approach will help to build trust and ensure that the policies implemented are well-suited to the needs of all affected communities.

[23] 2016 Open Space Conservation

[24] 2016 Open Space Conservation.

Climate change has emerged as one of the most pressing issues of our time, and cities are at the forefront of the fight against it. As significant contributors to and primary victims of climate change, urban centers worldwide have taken up the mantle of leadership in climate adaptation. These pioneering strategies may serve as blueprints for others. The role of local policies and organizations in urban climate adaptation is paramount, marking a necessary shift towards integrated, comprehensive strategies that encompass not just the physical but also the socio-economic impacts of climate change.

The evolution of climate policies in New York City from PlaNYC 2030 to OneNYC 2050 exemplifies this shift towards more inclusive, comprehensive planning that anticipates future climatic shifts and integrates public engagement and equity into the core of its strategy. New York City's efforts are a testament to a crucial transition from reactive to proactive policy-making in urban environments.

By integrating green infrastructure, improving public transportation, and engaging communities, New York City strives to create a resilient urban fabric that withstands climatic threats while enhancing the quality of life for all its residents. These efforts underscore the city's commitment to surviving future challenges and thriving through them.

The importance of resilience and equity cannot be overstated. Policies that fail to address the socio-economic dimensions of climate change risk exacerbating vulnerabilities and inequities within urban populations. Therefore, a resilient city is marked by its infrastructure, social cohesion, and economic stability.

Analyzing Policy Dynamics and Stakeholder Engagement: The dynamic solutions highlighted throughout this chapter reflect a growing recognition of the complex, interlinked challenges that urban centers face. Adaptive measures, whether they pertain to infrastructure, social policies, or regulatory frameworks, are increasingly informed by a comprehensive understanding of climate change as a pervasive influence on urban life.

Stakeholder engagement emerges as a pivotal theme in effective climate adaptation. The role of community-based strategies in enhancing climate governance is of utmost importance. As cities like New York progress, the integration of diverse community voices into planning and implementation processes remains a crucial aspect. This inclusivity ensures that the solutions developed are not only sustainable but also equitable, addressing the needs of the most vulnerable populations.

As this chapter concludes, the narrative transitions from the specific policies and actions undertaken by cities like New York to practical recommendations for implementing these strategies on a global and local scale. Chapter 5 will delve into new recommendations for urban climate challenges like NYC's current ones, analyzing how international frameworks, hybridized collaborations, and global policy initiatives influence and enhance local actions. The discussion will include how cities worldwide network and collaborate to effectively share knowledge, resources, and strategies to combat climate change. This perspective is crucial as it highlights the proactiveness needed of urban centers in the face of global challenges and underscores the importance of collective action in achieving climate resilience. By understanding the hybridized context in which local actions are situated, we can better appreciate the complexities and the critical need for integrated, comprehensive approaches to urban climate adaptation.

Chapter V: Implementing Change

Addressing the Issue Head-on: This paper has demonstrated the main issues surrounding SLR and coastal erosion and provided the historical background, economic analysis, and current policy in addressing sea level rise and coastal erosion. In addition, finding a clear and simple solution may be infeasible due to the complex and multifaceted nature of addressing localized climate problems. However, this chapter will present solutions to mitigate future and worsening climate scenarios regarding SLR and coastal erosion by implementing a combination of NBS systems, Gray adaptation, and Pink adaptation to create a new climate adaptation, mitigative, or mitigative climate solution. While these solutions may not encompass one hundred percent of climate problems, they will demonstrate their ability to efficiently address SLR and CE most effectively and feasibly aimed at reverting coastal erosion to halt the threat of SLR while being as cost-effective and environmentally supportive as possible. Breaking down the components that comprise mitigative techniques is essential in understanding the philosophy behind mitigation.

Mitigating future climate change involves building back a self-sufficient ecosystem, an ecosystem built to withstand the effects of climate change and reverse it by reclaiming lost ecosystems and reinstating keystone organisms that will contribute to the stability and proliferation of increased green areas. While natural cycles are usually the driver of sustainable ecosystems, because of human-induced climate change, the additional support of external forces is now required to meet climate balance.

Re-defining Nomenclature: Current nomenclature around mitigation within climate initiatives are:

> "As there is a direct relation between global average temperatures and the concentration of greenhouse gases in the atmosphere, the key to the solution to the climate change problem rests in decreasing the amount of emissions released into the atmosphere and in reducing the current concentration of carbon dioxide (CO_2) by enhancing sinks (e.g., increasing the area of forests). Efforts to reduce emissions and enhance sinks are referred to as "mitigation."" (UNFCCC)

As this research thesis has presented, climate change is a dynamic and ever-changing threat where many nuanced variables play into a larger scheme. Focusing a definition to define a single aspect of climate change presents problems as it limits the scope of use in defining initiatives. In addition to the recommendations put forth, this thesis also recommends expanding and including the nomenclature of mitigation within climate initiatives to include decreasing the threat of extreme climate change. This step away from limiting the scope of mitigation to CO_2 reduction presents an opportunity to expand safe nets of climate adaptation and mitigation strategies.

The importance of forming better nomenclature that reflects the fluctuating fluidity of climate change creates more than a better understanding of climate change initiatives. It allows for the genesis of new ideologies and philosophies in approach to climate change and stability. Building upon the complex relationship between nomenclature and narrative within the context of climate initiatives, the discourse on redefining terms such as "Anthropocene" underscores a critical intersection where scientific understanding and societal narrative collide and coalesce. As Rebecca Evans highlights in her examination of the "Anthropocene" concept, the term becomes a narrative device that offers a new way of understanding our epoch, characterized by human impact on the Earth. She states, "nomenclature such as 'Anthropocene' can be science fictional" in that it "does not simply prompt critical thinking; [it] calls up novel narratives" (Evans 2018, 487).

This perspective suggests that we can better encapsulate the diverse and dynamic nature of climate challenges by broadening the definition of terms like "mitigation" and "adaptation" within climate discourse.

Moreover, the redefinition of such terms can foster greater inclusivity and resilience in our approaches to climate change. By adopting a more expansive lexicon, we can encompass a variety of strategies that address the multifaceted impacts of climate change, not just CO2 reduction but also adaptation measures that enhance community resilience against extreme weather events. This approach aligns with the need for "narratives that integrate new understandings of societal and environmental interdependencies," as Evans noted.

The call for an expanded nomenclature also reflects the urgent need to embed these terms within policy and practice frameworks more effectively. By reshaping the language, we use, we can shift the narrative from one of mere survival or mitigation to one of proactive adaptation and transformation. This shift in narrative is crucial for inspiring broader public engagement and support for climate policies, leveraging the "entertaining power of narrative both to instruct and to galvanize its readers," as Evans mentions in her analysis of climate fiction.

Additionally, an inclusive approach to nomenclature could bridge the gap between diverse scientific disciplines and the public, fostering a more unified understanding of climate issues. As climate challenges are inherently complex, involving various ecological, social, and technological factors, a broader set of terms could facilitate better interdisciplinary collaboration and public comprehension.

Lastly, this expanded nomenclature would also resonate with the global nature of climate change, acknowledging that the impacts and solutions are varied across different regions and cultures. Such a linguistic shift could enhance global cooperation by providing a common framework that respects and integrates local knowledge and practices.

In conclusion, as Evans suggests, redefining nomenclature in climate discourse is not merely a semantic exercise but a strategic endeavor that can significantly influence the narratives we construct about our relationship with the planet. By broadening our climate vocabulary, we can enhance the efficacy, inclusivity, and resonance of our global response to climate change, ensuring that our narratives and actions reflect the complexity and diversity of our challenges.

Understanding the Philosophy of Mitigative Climate Solutions: Building back an ecosystem to self-sustainable levels is a daunting undertaking. However, when narrowing the scope of focus to address one variable at a time, solutions become more apparent. In the case of New York and SLR/CE, we can break down the issue into SLR and CE variables and their cause and effect. In addressing SLR, the main issue is the potential displacement, destruction, and economic toll rising water will have on densely populated areas of New York. Current initiatives focus on the combination of strategic retreats and the employment of physical barricades to halt the encroachment of SLR. However, as discussed in previous chapters, these initiatives take on a social cost (the displacement of individuals situated near the coastline) and an economic cost (the maintenance and constant adaptation to new climate threats), none of which are aimed at building back an ecosystem or building an ecosystem at all. Considering CE, the main threat again is the loss of infrastructure, land, and economic strain from not the rise of sea level but the erosion of land mass from water currents, with the primary response being strategic retreat.

Neither case has addressed the central issue of stopping either cause; instead, it is adapted to. This philosophy of constantly adapting may prove helpful in the cause of biological evolution. However, it falls short when addressing nature as a whole when global problems are applied to localized levels. When applying a more mitigative stance, mimicking solutions from natural cycles and localizing them to mimic the nuance of local systems allows for a complete, self-sufficient, and sustainable operation loop. Imitating natural processes that allow the propagation of other positive natural cycles to happen naturally may be the most feasible way of actively and passively addressing areas of climate change. The following section will break down a mitigative approach to New York City's issue of SLR and CE contrasting benefits and issues in application.

It is crucial to underscore the benefits of adopting nature-based solutions (NBS) that go beyond merely adapting to changes, focusing instead on systemic restoration and resilience. By imitating the self-regulating mechanisms of natural ecosystems, such as wetland restoration or the creation of living shorelines, New York can turn the tide against both SLR and CE. These NBS strategies not only help in buffering against the impact of rising sea levels and increased coastal erosion but also enhance biodiversity, improve water quality, and increase carbon sequestration, contributing holistically to the resilience of urban environments. The philosophy behind these approaches aligns with the broader principles of sustainability, which emphasize the integration of ecological, social, and economic dimensions to foster environments that can sustain themselves and their populations over time. By employing NBS, New York can create a robust framework for urban planning that addresses the immediate threats of SLR and CE while providing long-term benefits supporting ecological and community health. This integrated approach ensures that solutions do not merely shift problems from one area to another but address them at their source, thereby mitigating potential negative impacts on the community and the local economy.

Localizing climate solutions by adapting them to the specific characteristics and needs of New York's diverse neighborhoods can lead to more effective and acceptable outcomes. Each neighborhood has its unique geographical, ecological, and social context, which must be considered when designing interventions. This localized approach not only ensures that interventions are more effective but also fosters community engagement and ownership, crucial elements for the success and sustainability of any long-term climate strategy. This sense of community involvement is key to ensuring the success of these strategies.

To delve deeper into the philosophy of these mitigative strategies, it is essential to understand the pivotal role of adaptive management in the implementation of NBS. Adaptive management allows for the continuous monitoring of implemented solutions, with adjustments made as necessary to accommodate changing conditions and new scientific findings. This approach is particularly pertinent in dealing with climate change, where uncertainties abound, and conditions evolve rapidly. By embracing a philosophy that views intervention strategies as dynamic rather than static, New York can create a living system of defenses that grows stronger and more adept at protecting its landscape and its people over time. This adaptive approach instills confidence in the effectiveness and longevity of these strategies.

Proposed Mitigation Framework Combating SLR and CE in New York: Mitigation strategies focusing on SLR and CE in New York City can be broken down into Strategic Natural

Based Solutions, Gray Support, and Conducive Policy. In using strategic NBS, it is vital to understand the localized natural process of a problem area and the different fauna that contribute to and support that ecosystem. NBS, in this case, does much of the heavy lifting but also introduces a level of variability that other components of mitigation solutions do not, as it necessitates relying on the ecological niches of certain organisms to achieve climate change mitigation. For instance, employing oyster reefs[25] in strategic locations throughout New York harbor can alter coastline currents by creating natural reef systems to subdue their erosive nature entirely. In addition, the restoration of salt marshes around New York City contributes to the build-up of beaches, shorelines, and estuaries, allowing for more buffer space between currents and inhabited land use. Last, a more hypothetical approach would be the induction of frost-resistant mangroves along New York City's coast to protect against storm surges, hurricanes, land loss, and rising sea levels. With many of these solutions also come a secondary benefit; in the case of oyster reefs, oysters' fantastic ability to filter large amounts of water can help depollute New York's harbor water, reduce the amount of microplastics, and a potential food source if water contaminants are within safe levels. Salt marshes act as bio-hotspots for many key organisms and sequester large amounts of carbon into their system. They act as foundational ecosystems that support many ecological roles that can extend to climate solutions. Finally, mangroves offer more than just tidal barriers; they also contribute to bio-diversity growth, natural resources, carbon sequestering, and reef/ beach building.

However, as with any natural solution, it is crucial to realize the potential issues that may arise from some solutions. While the propagation of native species will not hurt NBS initiatives,

[25] "Billion Oyster Project." n.d. Billion Oyster Project. https://www.billionoysterproject.org.

it is when non-native species (i.e., mangroves) are introduced into an established ecosystem that extra precautionary measures are ensured not to allow the introduction of predatory organisms that out-compete native organisms.

The next step is the employment of Gray support; in an attempt to move away from Gray adaptation or Gray infrastructure, Gray support emphasizes Gray's usage role as a support system rather than a complete solution. Gray support relies on NBS systems to address many climate issues by mainly acting in conjunction with NBS. In application, this could take the form of an infrastructural sea wall project that relies on attached oyster reefs to act as A.) the primary foundational support of the wall and B.) mitigate the need for future wall maintenance by naturally rebuilding areas of the wall. Some NBS solutions, like the Mangrove, do not require gray support. However, in restoring Salt Marshes, the application of gray support can increase the area of the marsh by temporarily blocking intense oceanic surges of erosive variables until the intended area is brought back to restorative levels, and Gray support systems can either be removed or incorporated into the system.

Lastly, implementing conducive policy that allows for the propagation of mitigative techniques is required to scale mitigative applications efficiently. Policy must incorporate public and private incentives and mandates that allow for the investment, security, and benefits these solutions offer. Local governments must incentivize private corporations to practice mitigative initiatives and allow public organizations to engage in mitigation efforts. The policy should create the framework necessary for the proliferation of an economy around mitigative solutions. This shift in perspective will cause social and private interest to increase in mitigative designs and applications. Policy needs to shift from focusing on climate change adaptation to the future and mitigation.

Incorporating mangroves and oyster reefs into coastal protection strategies in New York presents a multi-faceted approach that enhances the resilience of coastal areas against sea level rise (SLR) and coastal erosion (CE). Integrating these natural systems with gray infrastructure can provide substantial economic and ecological benefits. For example, Verhagen and Loi highlight the cost-effectiveness of mangroves, noting that "mangroves in front of a coastal defense may lower the construction and maintenance costs of the defense" (Verhagen and Loi 2012). This statement underscores the potential for significant reductions in financial outlays for coastal defenses, which is crucial for long-term sustainability.

Oyster reefs complement the benefits provided by mangroves by mitigating wave action and promoting sediment deposition, which strengthens coastlines. Fivash et al. detail oyster reefs' protective capabilities, explaining that they "reduce coastal erosion in the intertidal and form fringing reefs near salt marsh edges to protect them against lateral retreat" (Fivash et al. 2021, 2). These reefs function to decrease the energy of incoming waves and enhance the shorelines' stability by trapping sediments that would otherwise be eroded away. Scientific research can optimize the strategic placement of these natural barriers. Verhagen and Loi suggest that a well-designed mangrove belt can significantly reduce wave attacks on coastal structures, lowering the necessary height and robustness of sea walls (Verhagen and Loi 2012, 1). This employment of oysters can reduce costs for coastal defense infrastructure by minimizing the need for extensive physical barriers, which are often expensive to build and maintain.

Integrating gray infrastructure with these natural solutions offers a dynamic and adaptive approach to coastal defense. Gray support structures such as sea walls can be designed to work in conjunction with biological systems, enhancing the longevity and effectiveness of the defenses. For instance, oyster reefs could be employed as standalone barriers and as supportive bases for sea walls, reducing the erosion at their base and extending their lifespan. Policies supporting the implementation of such integrated management strategies are critical. They should provide incentives for adopting Natural Solutions (NBS) and ensure flexibility in policy frameworks to incorporate innovative approaches such as combining mangroves and oyster reefs with traditional infrastructure. Moving from reactive to proactive management in coastal defense policy involves planning for future conditions and potential threats rather than simply responding to current issues.

Ultimately, combining mangroves and oyster reefs with gray infrastructure strategies provides a cost-effective method of enhancing coastal resilience, promoting biodiversity, and supporting the ecological health of coastal areas. These integrated strategies should be underpinned by robust policy frameworks that encourage innovation, sustainability, and resilience, aiming to protect urban coastal landscapes against the increasing threats posed by climate change.

Conclusion: In this thesis, we have embarked on a comprehensive exploration of the daunting challenges posed by sea level rise (SLR) and coastal erosion (CE) in New York City. We dissect the multifaceted nature of these phenomena and the broad spectrum of responses they necessitate. As our cities face these escalating threats, it becomes increasingly clear that traditional adaptation methods, while necessary, are insufficient to address the underlying complexities of climate change and its impact on urban landscapes. The necessity for a proactive and integrative approach to mitigative strategies has never been more apparent. Throughout this study, we have delved into the historical, economic, and policy contexts that shape our current understanding and response to SLR and CE. We have seen that while past measures have been invaluable in providing immediate relief and protection, they often need to address the root causes of these issues or provide sustainable long-term solutions.

The proposed mitigation framework outlined in this thesis advocates for a holistic approach, combining Natural Solutions (NBS), Gray adaptation, and Pink adaptation. This tripartite strategy aims to curb the immediate threats of SLR and CE and foster an environment where urban resilience can flourish. By integrating the regenerative capacities of NBS with the robustness of Gray infrastructure and the inclusivity of Pink strategies, we can create a dynamic system that adapts and evolves in response to the needs of New York City's diverse communities. Moreover, this thesis argues for a redefined approach to nomenclature and narrative within climate policy and action. Expanding and refining the language we use to describe and discuss these issues can enhance public understanding and engagement, paving the way for more nuanced and effective policies. The discourse around terms like "mitigation" and "adaptation" needs to reflect the complexity of climate change and the interconnectedness of our ecological, social, and economic systems.

As we conclude, it is crucial to recognize that the journey toward a truly resilient and sustainable urban environment is iterative and collaborative. The challenges we face are not insurmountable, but they require concerted efforts across all sectors of society—governmental bodies, private entities, and individual citizens. Through our collective action and commitment to innovation, grounded in the lessons of the past and informed by the possibilities of the future, we can hope to forge a resilient path forward for New York City.

In sum, this thesis does not just call for a shift in how we respond to SLR and CE; it demands a transformation in how we conceive of and engage with our urban environments in the face of climate change. The strategies proposed here aim to catalyze that transformation, inspiring protective measures and proactive steps that enhance the livability, sustainability, and resilience of our urban landscapes. To end on a quote by the esteemed Richard Powers, "People aren't the apex species they think they are. Other creatures-bigger, smaller, slower, faster, older, younger, more powerful-call the shots, make the air and eat sunlight. Without them, nothing." (Powers 2021)

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