CLIMATE RESILIENT GALVESTON

Understanding climate vulnerabilities and adaptation strategies to build resilience

Arsum Pathak

NATIONAL WILDLIFE FEDERATION
Texas Coast and Water Program

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Layout and Design: Amal Ahmed

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The National Wildlife Federation presents this comprehensive assessment to empower local leaders and key stakeholders in the Galveston area with vital information on the anticipated impacts of climate change.

The purpose of this report is to provide local leaders and stakeholders with a comprehensive review of the climate conditions facing Galveston Island and an evaluation of proposed recommendations that are available to meet future challenges. We believe that equipping leaders with this information will facilitate decision-making that protects both the natural and built environments, allowing local communities, wildlife, and ecologies to thrive in the future. Comprehensive adaptation strategies, community engagement, and policy adjustments are essential to ensure the island's long-term resilience and sustainability.

The assessment consolidates the latest science on climate change-related risks, including socio-economic and environmental impacts on Galveston Island. We then outline adaptation strategies to mitigate the impacts on island communities and natural assets in the Galveston area. A summary of our key findings is below.

Sea Level Rise

Galveston Island is particularly vulnerable to sea level rise caused by warming in the Gulf of Mexico and melting glaciers in the Arctic. As the island is low-lying to begin with, its vulnerability is heightened by local land subsidence caused by oil, gas, and groundwater extraction. Galveston has already experienced a 2.18-foot sea level rise over the last century, which has accelerated more than 8 inches in the last 14 years since 2010. NOAA projects future rises of 3 to 8 feet by 2100, depending on ocean warming and ice melt rates. Extreme scenarios suggest potential uninhabitability, with coastal flooding, erosion, and submersion of wetlands and dry land.

Coastal Storms and Storm Surge

Over the past two decades, major hurricanes like Rita, Ike, and Harvey have struck the Texas coast, causing significant damage. Climate change is expected to increase the frequency of severe Category 4 and 5 hurricanes. Warmer sea surface temperatures contribute to storm escalation, higher moisture content, and increased rainfall. If a storm similar to Hurricane Ike were to strike in 2100, its storm surge would be 2.55 feet higher, and the impacted area would be 450 more square miles larger due to sea level rise and landscape changes.

High Tide Flooding

High tide flooding, linked to rising sea levels, occurs more frequently each year. Galveston experienced 3-8 high tide flood days per decade from 2010-2020. Predictions suggest the island could see a potential increase to anywhere from 29 to 121 days between 2030-2050. Under intermediate-high scenarios and without any adaptation measures, high tide flood days may reach 209 annually by 2050.

Extreme Temperature and Rainfall

Climate scientists predict that Texas will experience historically unprecedented warming by the century's end. Galveston could see between 2 to 21°F increase in extreme temperatures. Winter water temperatures in Galveston Bay have already warmed by 10% over the last 15 years, negatively impacting marine ecosystems. While annual average precipitation changes are predicted to be minimal, intense rainstorms—two or more inches of precipitation in a day—may increase between 2% and 14% based on varying climate change projections.

Climate Risks and Adaptation Needs

The coastal habitats of Galveston, crucial for buffering storms and providing numerous community benefits, are under threat from these projected changes. Future projections indicate further losses will occur due to rising sea levels and storm surges. The decline in critical wildlife and marine species, including blue crabs and oysters, reflects not only overfishing but also the compounding effects of climate-induced stressors such as changes in ocean pH, salinity, and temperature. Water quantity and quality in Galveston Bay are susceptible to extremes in weather events, leading to algal blooms, fish kills, and other environmental stressors. Sea level rise compounds these issues, putting at risk critical infrastructure and properties, with potential economic damages in the billions. This report highlights the uneven social vulnerability across the island, emphasizing the need for tailored resilience planning to address the varied impacts on different communities, including communities of color, older adults, refugees, immigrants, and renters. "Nature-based Solutions" (NbS)—known by such terms as natural infrastructure, natural defenses, ecosystem-based adaptation, or natural and nature-based features—can play an important role in community adaptation and resilience. The adoption of nature-based solutions for climate resilience faces challenges, including a lack of familiarity and technical training among community members and stakeholders. Concerns about effectiveness and a lack of regulations further impede the implementation of such projects. Showcasing successful examples of such projects, including the Sweetwater Nature Preserve and oyster reef restoration in Galveston Bay, can inspire confidence in new initiatives. Creating supportive social, policy, and legal environments will be crucial to moving projects forward.

Galveston after the Great Storm of 1900 (Library of Congress)

We have identified four pillars for advancing nature-based solutions: implementing on-the-ground projects, building community capacity, supporting climate jobs and training, and fostering a conducive regulatory and policy landscape. These pillars draw from existing plans in Galveston and examples from coastal planning efforts nationwide, tailoring strategies to Galveston's unique social, economic, and ecological contexts.

Pillar 1: Identifying and Implementing On-the-Ground Projects

We recommend that local leaders prioritize projects that protect and restore natural habitats that provide crucial ecosystem services such as flood control and carbon storage. Such projects may include living shorelines, offshore oyster reefs, and barrier beach and dune restoration. We have specifically highlighted the following projects for their ecological and social benefits: living shorelines, oyster reef restoration, salt marsh restoration, and urban planning policies that facilitate habitat connectivity. To successfully implement such projects, we recommend identifying potential locations that can replicate projects that have already proven successful.

Pillar One	1.1 Use living shorelines to stabilize shoreline edges, where appropriate. 1.2 Explore construction of offshore oyster reefs and beds to attenuate wave energy, reduce erosion, and improve water quality. -1.3 Protect and restore barrier beaches and dunes through renourishment and revegetation. 1.4 Restore degraded salt marshes and facilitate marsh migration. 1.5 Consider opportunities to establish habitat connectivity on and around local project sites. 1.6 Implement site-specific green infrastructure measures to mitigate stormwater runoff, reduce urban heat island effect, and improve water quality. 1.7 Prioritize low-impact development (LID) practices and conserve land to increase open space. 1.8 Sustain freshwater inflows.

Pillar 2: Building Community Capacity and Cohesion

Public support and buy-in are crucial components for the success of nature-based solutions. Leaders will need to engage communities and create outreach and educational opportunities to highlight the importance of these projects. We recommend that engagement and outreach are integrated early in the planning processes, ensuring that residents understand the ecological and social benefits that may be seen in their neighborhoods. We suggest that leaders and planners identify community champions to lead discussions on climate change and resilience planning; additionally we propose that city leaders and the philanthropic community create a liaison position to aid collaboration between these establishments.

Pillar Two	2.1 Develop strategies for enhanced outreach and education. 2.2 Empower grassroot champions to co-design nature-based projects. 2.3 Create a city-community liaison to align city leadership, non-profits, and philanthropic interests to enhance collaboration and coordination. 2.4 Coordinate with existing organizations to promote ecotourism.

Pillar 3: Climate Jobs and Training

Nature-based solutions can create employment opportunities in conservation and climate-related fields. We recommend initiatives that will encourage community science participation, as well as resilience training programs for city officials and project-based learning collaborations. These job training and creation programs can be supported through partnerships with educational institutions, environmental organizations, and existing federal programs. Informal training programs that promote backyard habitat development practices can also engage the public in conservation efforts.

Pillar Three	3.1 Support and develop opportunities for community science. 3.2 Launch a place-based resilience training program for city officials. 3.3 Implement project and place-based learning through existing collaborations and frameworks. 3.4 Encourage backyard habitat development practices.

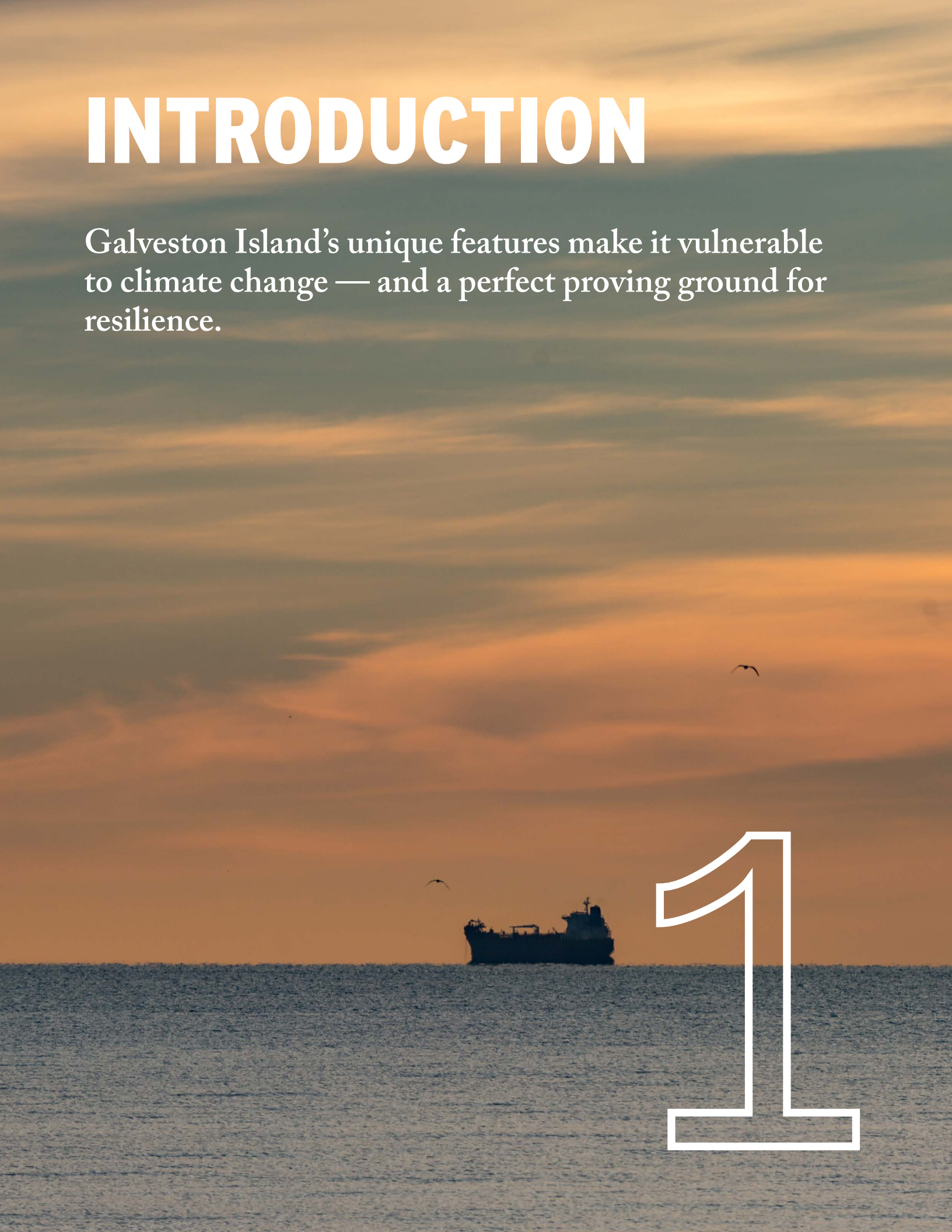
Pillar 4: Fostering a Conducive Regulatory and Policy Landscape

The policy framework needed to support nature-based projects must be strengthened to ensure the long-term success of these strategies. Government agencies and philanthropic organizations must be aligned on priorities and responsibilities; collaboration between these entities will be key to ensuring a coordinated response to climate change. We highlight the use of buy-outs and financial incentives to remove infrastructure from floodplains and the revision of building codes to account for climate change impacts. Additionally, overarching regulations that strengthen wetland protections, create transferable development credits and initiate comprehensive water resources management can all guide responsible development.

Pillar Four	4.1 Conserve land and use financial incentives to remove infrastructure from floodplains. 4.2 Update building codes to account for climate change impacts. 4.3 Incorporate the best available science on the impacts of climate change in policies, regulations and programs. 4.4 Create local wetlands protection bylaws and regulations. 4.5 Designate areas requiring special protection in light of climate change (e.g., beaches, wetlands, priority habitat) and limit new development in these areas. 4.6 Use transferable development credits to reduce risky coastal development. 4.7 Implement comprehensive water resources management such as One Water. 4.8 Create incentives for integrating nature in development. 4.9 Increase collaboration among local, regional, and state entities.

INTRODUCTION

Galveston Island's unique features make it vulnerable to climate change — and a perfect proving ground for resilience.



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The Galveston Area Context

Galveston is a long, narrow barrier island situated south of Houston, surrounded by Galveston Bay and the Gulf of Mexico. In Galveston Bay, fresh waters from the Trinity and San Jacinto Rivers mix with the tidal salt waters of the Gulf of Mexico to form the largest estuary along the Texas Coast. The island's abundant natural features, including seagrasses, wetlands, and coastal prairies, account for more than half of the island's land area and provide crucial habitat for plants and wildlife.

Galveston Island's low-lying nature and physical location make it extremely vulnerable to climate change induced-sea level rise and other extreme weather events. The history of the island is already punctuated by storms: Notably, in 2008, Hurricane Ike damaged more than 75% of the structures in Galveston; a century earlier, the Great Storm of 1900 caused the most natural disaster-related fatalities in the US to date. And while Hurricane Harvey did not hit Galveston in 2017, the extreme rainfall and catastrophic flooding that occurred in other parts of the state served as a reminder of the island's vulnerability to similar extreme events.

Despite its vulnerability, Galveston Island has retained its strong historic character. Much of the island's original architecture has been preserved through decades of storms. The island's thriving economy historically revolved around port activities, and today, the tourism industry attracts a significant number of workers and visitors. Additionally, the island hosts two major university campuses: the University of Texas Medical Branch, which is the oldest medical school in Texas, as well as a branch campus of Texas A&M focused on marine and coastal studies.

The National Wildlife Federation has developed this assessment to equip local leaders and key community stakeholders with information about the region's future related to climate change impacts. The assessment can provide a foundation for stakeholders to make informed choices and leverage funding opportunities to prepare for the present and future challenges the island may face. The assessment will also enable them to make decisions based on the best available science when it comes to investments in natural assets, protection of coastal environments for wildlife, and protection of their communities and the local economy.

The two main objectives of this assessment are:

- To synthesize the latest information regarding climate change-related risks and their socio-economic and environmental impacts on Galveston Island.
- To identify adaptation strategies to mitigate the impacts to island communities and natural assets in the Galveston area.

The Big Picture

Because of Galveston Island's physical conditions, it will experience sea level rise sooner and more acutely than many other coastal communities across the nation. Therefore, the island can serve as a proving ground for adaptation strategies. Past events have spurred investments and adaptations: the 1900 storm, for example, led city leaders to construct the sea wall and raise certain portions of the island. With growing climate risks, the limitations of relying solely on conventional infrastructure options (such as cost, failure points, continuous maintenance, etc.) are becoming all too evident. Additionally, the maladaptation caused by

Table 1. Existing Planning Efforts

Plan	Entity	Type of Entity	Year
The Galveston Bay Plan	Galveston Bay Estuary Program	Nonprofit	1995 (updated in 2018)
Comprehensive Plan	City of Galveston	Local Government	2003 (updated in 2011)
Master Drainage Plan	City of Galveston	Local Government	2003
Beach Access Plan	City of Galveston	Local Government	2004 (updated in 2020)
West Galveston Island Greenprint	The Trust for Public Land	Nonprofit	2007
Sustainable Neighborhood Development Strategies	Urban Land Institute	Nonprofit	2009
Strategic Master Plan	Port of Galveston	Local Government	2019
Galveston 2030	Vision Galveston	Nonprofit	2019
Coastal Texas Protection and Restoration Feasibility Study	US Army Corps of Engineers and General Land Office	Federal Government	2021
Hazard Mitigation Plan	City of Galveston	Local Government	2022
Galveston Bay Estaury Resilience Assessment Report	Houston Advanced Research Center	Nonprofit	2022
Texas Coastal Resiliency Master Plan	Texas General Land Office	State Government	2023

hard solutions can further compound the impacts of future extreme events. For example, seawalls and grade raising can cause an increase in localized flooding.

Over the last several decades, numerous civic groups and government agencies have developed resilience-related plans to guide Galveston Island through extreme events and future development. These plans do not always share the same goals and strategies. Bringing these various efforts into alignment is crucial, however, since government agencies, non-profits, community organizations and philanthropic institutions each play complementary roles in building resiliency. Table 1 on page 14 shows some examples of the municipal and regional resilience initiatives along with their lead planning entity.

Environmental and Economic Context

Galveston Island's natural habitats such as wetlands, seagrasses, and oyster reefs provide a range of benefits to the communities and wildlife that depend on them. These habitats act as the first line of defense to coastal climate impacts by buffering storms, attenuating waves, and slowing runoff– all of which can be considered climate adaptations. Additionally, the natural features also act as sinks for storing and sequestering carbon dioxide (a greenhouse gas responsible for causing an increase in global temperatures), a phenomenon known as blue carbon.

The natural features, thereby, offer both climate adaptation as well as climate mitigation benefits (see Table 2 below). These habitats also provide important economic services as well: Several of Galveston Bay's critical fisheries depend on these habitats for food and breeding. The island's natural features also provide recreational services for local residents and nearly 8 million visitors to the island every year.

Table 2. Ecosystem Services Provided by Natural Feaures in Galveston Bay

	Wetlands	Seagrass Meadows	Oyster Reef
Coastal Protection	Wave and surge attenuation, storm water retention, sediment Stabilization	Wave attenuation, sediment stabilization	Wave attenuation
Fisheries	Habitats for certain species	Habitats for certain species	Habitats for certain species, source of food for certain species
Blue Carbon	Storage and sequestration	Storage and sequestration	Storage and sequestration

Public, private, and nonprofit entities have worked to preserve these key ecosystems and natural features. For example, the Audubon Society established the Dos Vacas Muertas Bird Sanctuary in 2001; a nonprofit named Artist Boat has purchased and preserved 900 acres of coastal habitats including saltwater and freshwater wetlands, coastal prairie, relic dunes, sand and mud flats. Galveston Island State Park and the East End Lagoon Nature Park and Preserve (operated by the State of Texas and the City of Galveston, respectively) are popular recreational sites for tourists and residents. Galveston Island State Parks ranked the

highest in the state terms of yielding economic benefits through park revenues, tourism, and job creation in the state, according to the Texas Coastal Resiliency Master Plan (TCRMP, 2023) (See Figure 1 on page 17).

The Port of Galveston ranks as the nation's fourth-largest cruise market based on embarkations. Since 2018, the number of annual cruise ship calls has grown by more than 10%, according to the Texas Coastal Resiliency Master Plan. Cruise activity generated $71.5 million in passenger onshore spending and another $23.4 million in services in 2019. The Port of Galveston creates $1.4 billion in local business services revenue, $5.6 million in state and local taxes, and a multitude of business development opportunities (The Port of Galveston, 2022).

The commercial fisheries (blue crab, brown shrimp, southern flounder) industry supports not only commercial harvesters but also seafood processors, seafood distributors, grocers, and restaurants. In 2020, Galveston ranked highest in the landed value of commercial fishery harvests in Texas ($51.2 million) (NOAA Fisheries, 2020). Boating on Galveston Bay is also a popular activity for millions of visitors, including local community members from Galveston and Harris counties, with sport fishing and party-boat fishing as the top activities for residents, making up over 80% of all bay activities (Table 3).

Table 3. Galveston Bay Boating Use by County of Residence and Top Activities

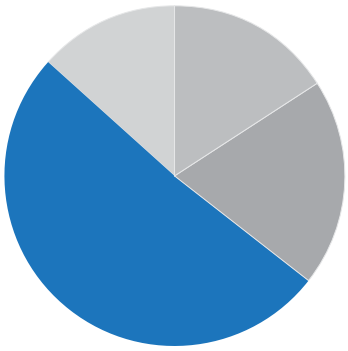
Source: Texas Coastal Resiliency Master Plan

County of Residence	% of Total
Harris	30
Galveston	20
Brazoria	14
Fort Bend	7
Montgomery	5
Chambers	4
Liberty	2
Tarrant	1

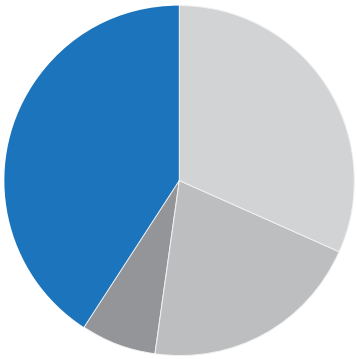
Activity	Participation %
Sport fishing	62
Party-boat fishing	21
Sailing or pleasure riding	7
Other	5
Tournament fishing	2
Work boat	2
Commercial crabbing	1

Figure 1. Economic Impacts from Coastal State Parks

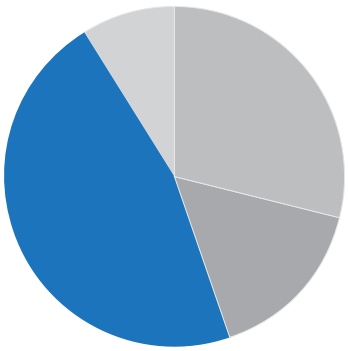
Source: Jeong and Crompton, 2019.



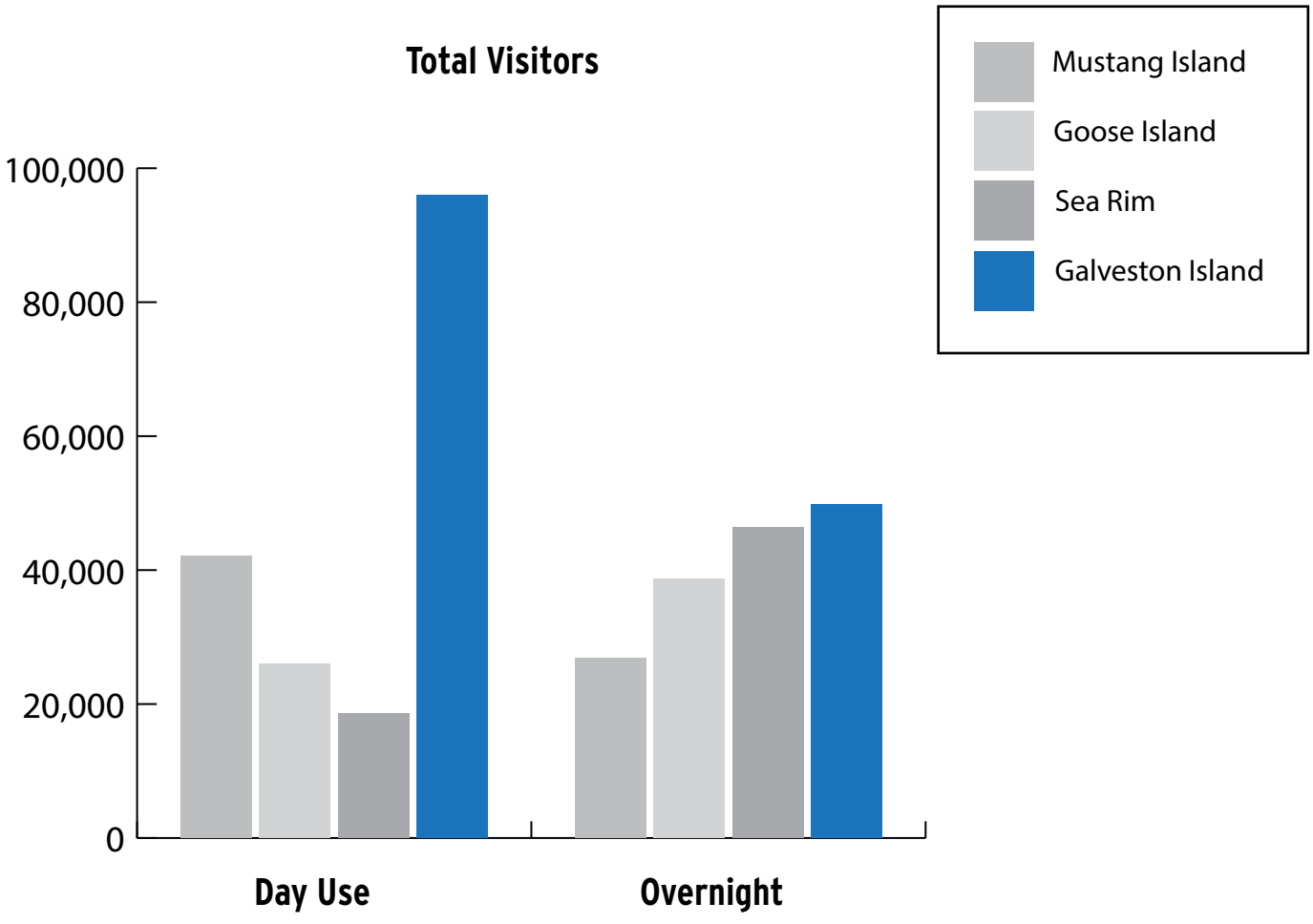
Coastal State Parks Revenue



Impact on Output



Impact on Labor Income



Adaptation Needs and Opportunities

As climate change affects communities across the country, the need for effective approaches to reduce climate-related risks is increasingly evident.

Historically, government agencies have favored the use of structural or engineered solutions–such as levees, sea walls, and stormwater drainage channels–to address risks from natural hazards. For example, the United States Army Corps of Engineers' (USACE) Coastal Texas Study aims to protect Galveston Island and the Houston Ship Channel through a $57 billion project utilizing storm surge gates and a ring barrier system around Galveston Island, among other components. If funded, this project would be the largest Army Corps project to date. Despite its estimated price tag, concerns have been raised by experts from several organizations about the plan's identified engineering solutions and the models used to calculate risk. For example, USACE's plan is designed for a storm that has a 100-year return period, meaning that in any given year there is a 1% probability of a storm that is severely occurring.

However, the study relies on NOAA's intermediate-low projections for sea level rise. More recent research, such as NOAA's 2017 and 2022 Technical SLR reports, rely on six different scenarios of sea level rise, ranging from low to extreme, for coastal planning. The USACE Coastal Texas Study may underestimate the risks that communities will face. Further, areas are left out of the footprint of the project like San Luis Pass and the Channelview neighborhood—posing both risks to project effectiveness due to erosion along the West End of Galveston and equity issues for areas left outside of the project footprint due to the USACE's benefit-cost analysis.

Galveston Seawall

Illustration of vertical lift gates proposed in the Coastal Texas Study (US Army Corps of Engineers)

The limitations of solely relying on hard infrastructure, touted as "silver-bullet" approaches in an era of rapid climate change, are becoming all too evident. Recent extreme weather events have caused widespread failures among the nation's already stressed and deteriorating infrastructure. Additionally, there is a rising gap between the past climatic conditions most of these structures were designed to accommodate, and the conditions they eventually must confront. Indeed, the number of billion-dollar climate and weather-related natural disasters has been increasing dramatically, with more than twice the number of such costly disasters occurring in recent years compared with the 40-year average (NOAA, 2021).

"Nature-based Solutions" (NbS)—known by such terms as natural infrastructure, natural defenses, ecosystem-based adaptation, or natural and nature-based features—can play an important role in community adaptation and resilience. These solutions also offer a dual benefit for communities: they can ameliorate climate-related risks while enhancing the quality of life for residents. Nature-based solutions are becoming increasingly popular as planners and stakeholders come to recognize their benefits.

Nature-based solutions can encompass a wide range of options, from reliance on still-intact natural systems or these key ecosystems, to the use of engineered systems designed to emulate natural system functions. Nature-based approaches can also be used in concert with structural options to form hybrid or "green-gray" systems for risk reduction. However, to incorporate NbS into community adaptation and resilience plans, decision-makers should consider several factors; these include the appropriateness of the project in a given context, the effectiveness against specific risks, and the long-term sustainability of the project in the face of climate change and other environmental stresses.

DEFINING CLIMATE RISKS

Sea level rise, temperature changes, and hurricane risks present major challenges for Galveston Island.

2

The State of Climate Science

Evidence of climate variabilities are widespread and scientifically documented at the global (Church et al., 2013; IPCC, 2013), national (Romero-Lankao et al.,2014), and state (Kloesel et al., 2018; Runkle et al., 2022) levels. Along the Texas coastline, global warming and climate change will lead to increasing risks from sea level rise and storm surge events. The Gulf of Mexico has already warmed by 0.6°F (0.31°C) from 1982 to 2006, and sea levels have risen at the rate of 2 to 3 mm/year from 1950 to 2000 due to ocean thermal expansion and glacier mass loss (Hoegh-Guldberg et al., 2014). The Texas Climate Summaries (Runkle et al., 2022) drafted as part of the latest U.S. National Climate Assessment provides a summary of increasing climate risks in the state, including:

- Temperatures in Texas have risen almost 1.5˚F since the beginning of the 20th century. Historically unprecedented warming is projected during this century, with associated increases in extreme heat events.
- Although projected changes in annual precipitation are uncertain, increases in extreme precipitation events are predicted. Higher temperatures will increase soil moisture loss during dry spells, increasing the intensity of naturally occurring droughts.
- Future changes in the number of landfalling hurricanes in Texas are difficult to project. However, as the climate warms, hurricane rainfall rates, storm surge height due to sea level rise, and the intensity of the strongest hurricanes are all projected to increase.

Sea Level Rise

The entire Texas Coast, including Galveston Island, will be affected by rising seas caused by the warming Gulf of Mexico and melting glaciers. The upper Texas Coast is particularly vulnerable due to simultaneous local land subsidence caused by oil, gas, and groundwater extraction. As a result, sea level rise in Galveston is higher than the average along the rest of the coast, with the island seeing a 2.18 foot increase over the last century (Figure 2). This rate of change has accelerated in the last ten years, with a recent analysis suggesting an extraordinary rate of sea level rise: 8 inches in 14 years since 2010 (Washington Post, 2024).

NOAA's most up-to-date projections suggest that Galveston Island may experience between 3 to 8 feet of sea level rise by the end of the century, depending on the rate of ocean warming and ice melt, as projected by the Sea Level Rise and Coastal Flood Hazard and Tools Interagency Task Force. The Task Force comprises 23 senior scientists and experts from NOAA, NASA, Environmental Protection Agency, U.S. Geological Survey, Federal Emergency Management Agency, and Army Corps of Engineers. Figure 4 on page 22 demonstrates relative sea-level rise scenarios by 2100.

In the extreme scenarios outlined above, if sea levels rise without any adaptation, coastal flooding will be more severe, beaches and community assets will erode. Eventually, both wetlands and dry land may be submerged, making the island uninhabitable for residents and wildlife.

Figure 2. Relative Sea Level Rise Trend in Galveston

Source: NOAA

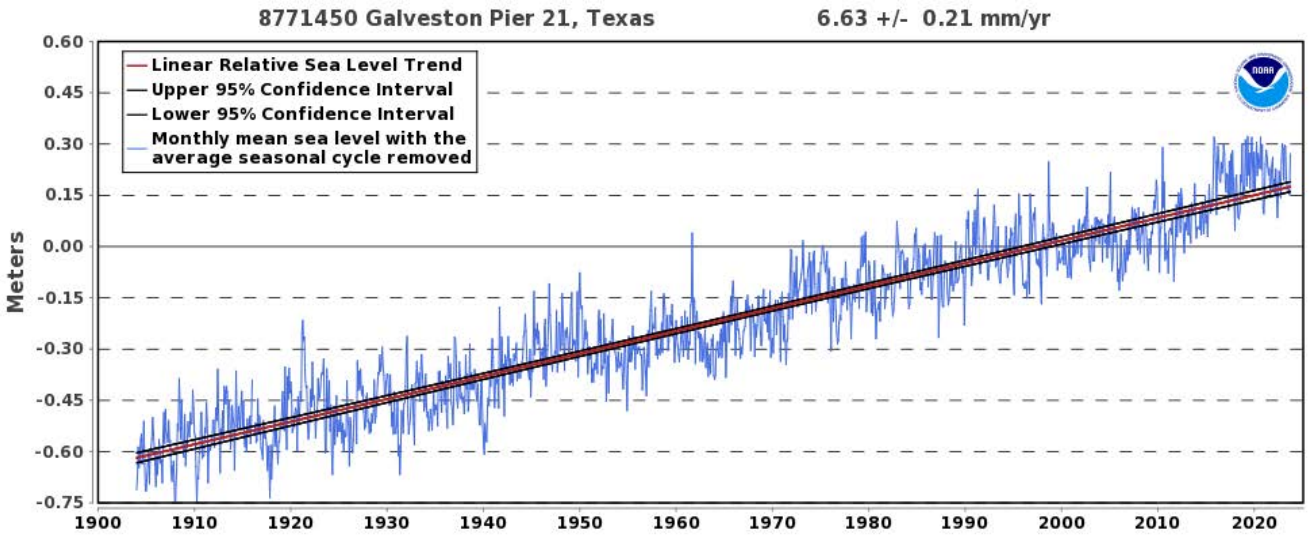
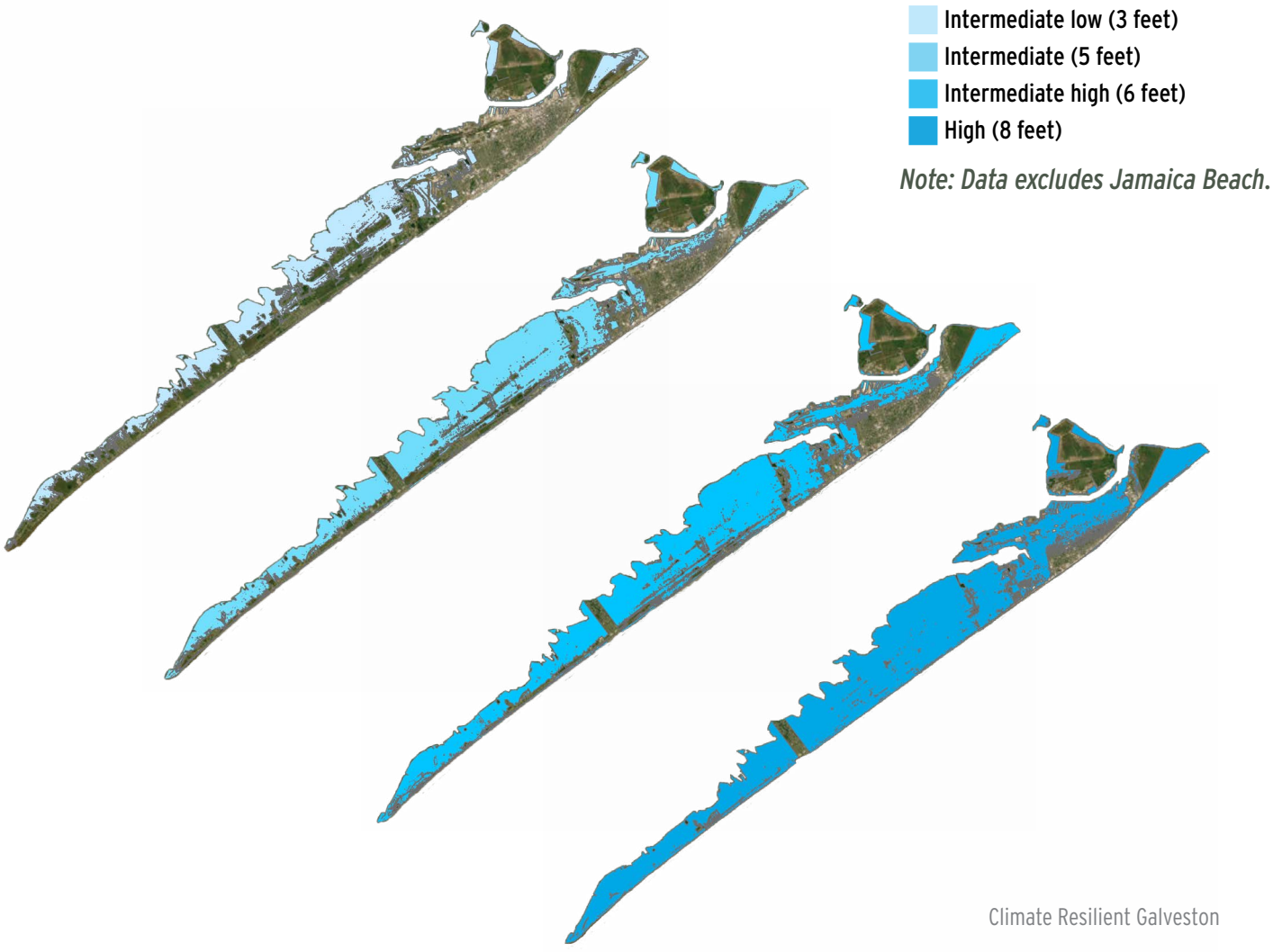


Figure 3. Inundation Caused by Sea Level Rise (2100 Scenarios)

Source: NOAA



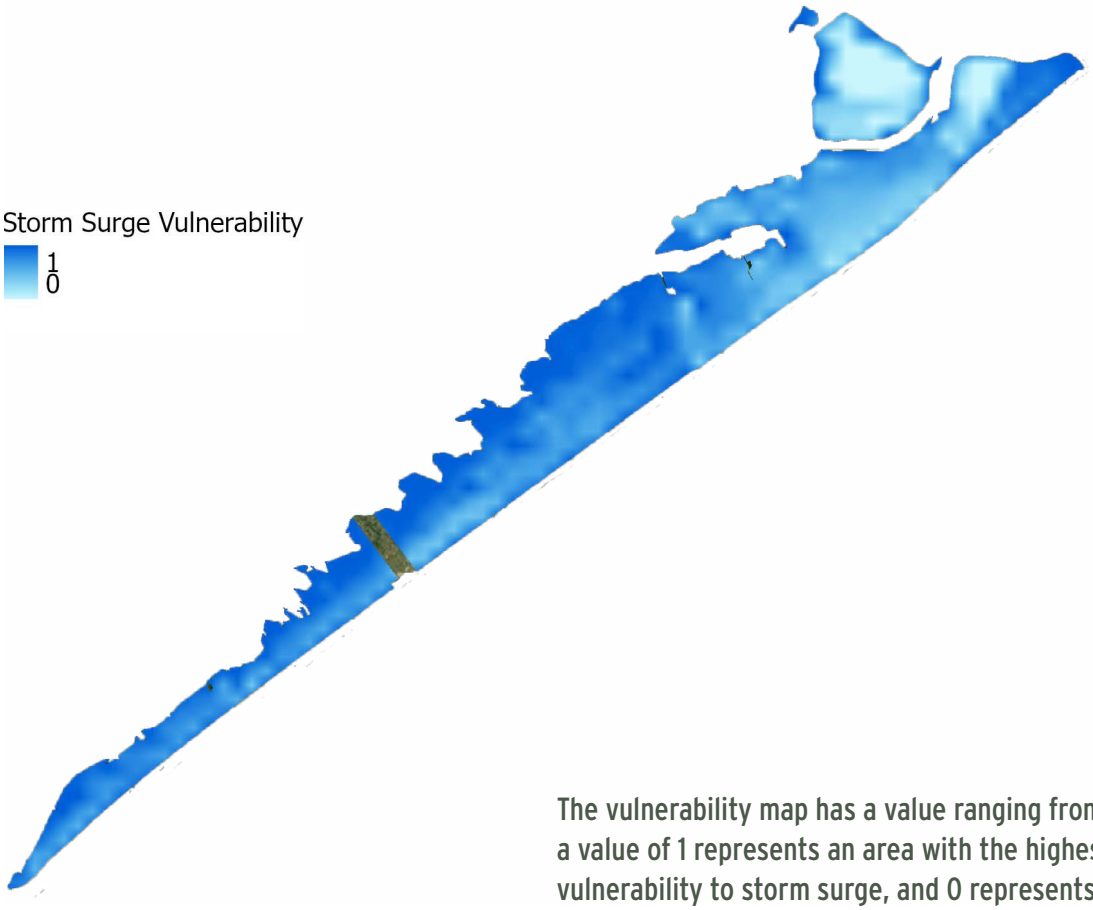
Note: Data excludes Jamaica Beach.

Coastal Storms and Storm Surge

Over the past 20 years, several major hurricanes have struck the Texas coast: for example, Hurricane Rita (Category 3) in 2005; Hurricane Ike (Category 2) in 2008; and most recently, Hurricane Harvey (Category 4) in 2017. These storms caused widespread coastal flooding, extreme rainfall, and dangerously high winds. Hurricane Ike's 15-foot storm surge caused $37.5 billion in damages. Much of the island will be susceptible to storm surge in the future (Figure 4).

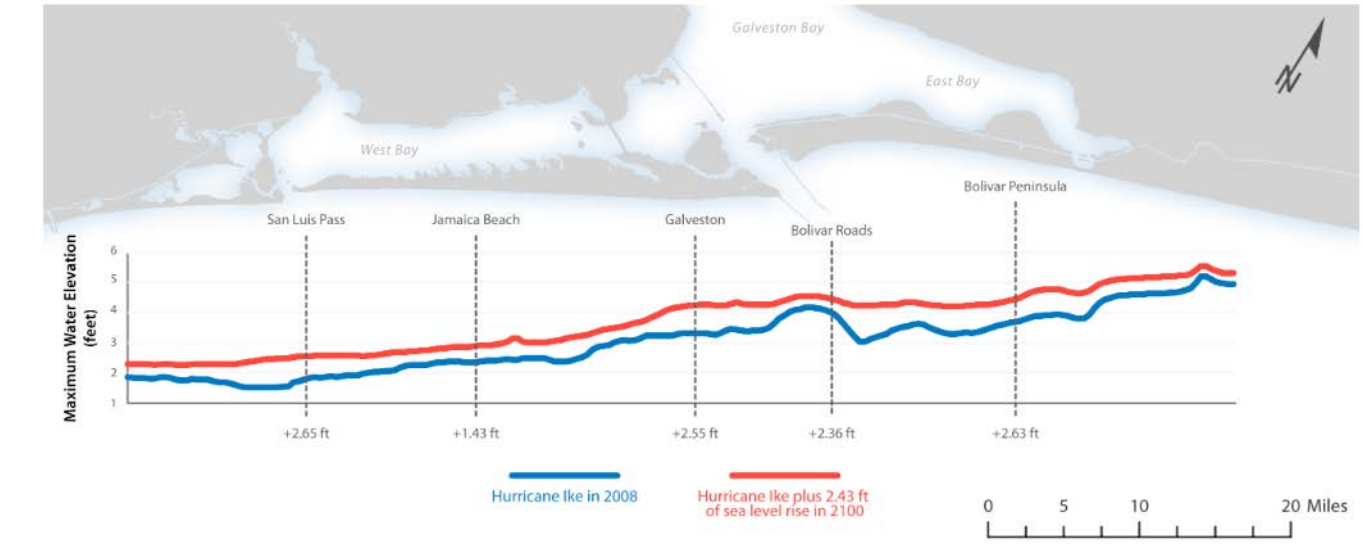
Climate change is expected to increase the frequency of severe Category 4 and 5 hurricanes such as Harvey (Kossin et al., 2020). Warmer sea surface temperatures will make small storms more easily escalate into larger and stronger storms, and will cause a higher moisture content resulting in more rainfall. As storm surge is placed on elevated water levels, the damage potential of these hurricanes will further increase. In an analysis conducted by the Harte Research Institute at Texas A&M University-Corpus Christi, if a storm similar to Hurricane Ike were to hit Galveston in 2100, its storm surge would be 450 sq. miles greater than what the island experienced in 2008; the storm would also result in an additional 2.55 feet of storm surge height due to sea level rise and landscape changes (Figure 5).

Figure 4. Storm Surge Vulnerability



The vulnerability map has a value ranging from 0 - 1, where a value of 1 represents an area with the highest vulnerability to storm surge, and 0 represents an area with the lowest storm surge vulnerability. Note: Data excludes Jamaica Beach.

Figure 5. Changes in Total Inundation Posed by Hurricane Ike With Sea Level Rise



Extreme Temperature and Rainfall

Texas will experience historically unprecedented warming by the end of this century, leading to increases in the number of extremely hot days and decreases in the number of extremely cold days. In Galveston, extreme temperatures on the hottest days of the year are projected to increase by 2 to 21°F, according to the Climate Explorer tool created by the National Environmental Modeling and Analysis Center (NEMAC) through statistical climate downscaling.[1] In Galveston Bay, winter water temperatures - the lower range of temperatures that plant and animal species have to endure to be able to live in the bay - have increased more than 10% in the last 15 years (GBF and HARC, 2023).

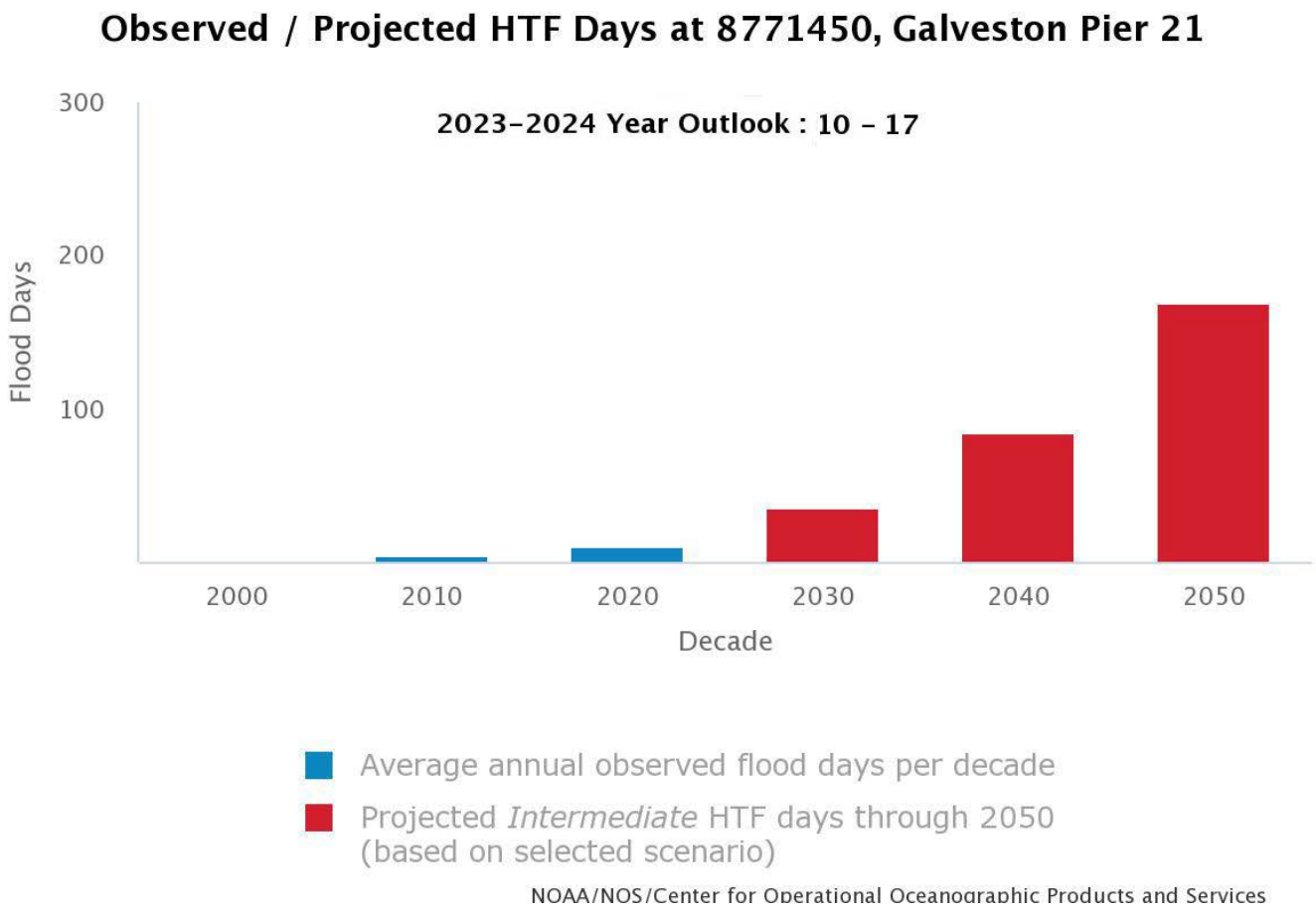
Changes in annual average precipitation are generally projected to be small, but an increase in extreme precipitation is likely. Historically, Galveston averaged two intense rainstorms per year. Annual counts of intense rainstorms—those that drop two or more inches in one day—vary significantly and are projected to have between a 2% decrease and a 14% increase based on the global greenhouse gas emissions scenarios.

1 These ranges are a result of downscaling a variety of global climate models and potential future scenarios based on future greenhouse gas emissions. For instance, a conservative, best-case scenario with low greenhouse gas emissions will lead to lower rate of increase in extreme temperature and flood days as compared to a worst-case scenario that involves a high concentration of greenhouse gas in the air and no policies enacted.

High Tide Flooding

High tide flooding, sometimes referred to as nuisance flooding, sunny-day flooding, or king tide flooding, is occurring more frequently every year as sea levels continue to rise. This type of flooding is defined as the excess accumulation of ocean water at high tide that covers low-lying areas—anywhere from 1.75 to 2 feet above the daily average high tide—causing water to overflow onto streets or bubble up from storm drains. Galveston experienced 3-8 high tide flood days per decade between 2010 to 2020 (Figure 6).

Figure 6. Observed and Projected High Tide Flood Days in Galveston



WHAT'S AT RISK?

Climate change will affect the Island's ecology, as well as its socio-economic fabric. The impacts may be felt unequally across the region.

3

Coastal Habitats and Land Cover

A range of coastal habitats in Galveston provide hazard risk reduction through buffering storms, attenuating waves, soaking and slowing runoff. They also provide community benefits such as improved air quality and outdoor recreation to Galvestonians. However, many of these ecologically significant areas are being impacted by development and land use changes. According to the NOAA's Coastal Change Analysis Program (C-CAP), the West Galveston Bay watershed experienced a 25.72% increase in development and 33.58% increase in impervious surface area between 1996 to 2013. During the same time period, total wetland cover in the watershed has declined by nearly 4% (7.67 square miles) with the largest decline in freshwater wetlands by 10.37%. Much of the lost wetlands are transformed to development followed by conversion into open spaces and water due to erosion caused by rising seas.

In the future, climate change-induced sea level rise and storm surge coupled with development pressures will lead to further loss of coastal habitats on the island. According to an analysis conducted by the Texas General Land Office, almost 13% of Galveston's land area is susceptible to conversion into future open water due to sea level rise by 2100 under an intermediate-low scenario (TCRMP, 2023). Under an intermediate-high sea level rise scenario, nearly a quarter of the island is vulnerable to conversion into open water. About 17% of the existing coastal environment (such as freshwater wetlands, transitional wetlands, regularly flooded estuarine wetlands, tidal flats, and beach/foredune systems) is at risk of flooding and erosion under the intermediate-low sea level rise scenario, mainly along the bay shoreline where the largest wetland extent is located, and the strip of beaches and foredunes on the Gulf side.

The loss of natural features will also mean the loss of the ecosystem services (benefits to human health, wellbeing, and environment that communities receive from nature) that they provide. Currently, wetlands around Galveston Bay can hold more than 300 million m^3 of water during a storm that generates a 1 m surge. They also store 29.21 million metric Tons C/ha of carbon dioxide. Losing these important systems poses the threat of cascading impacts, as carbon emissions may ultimately increase from inundated salt marshes or areas converted into open water (Guannel et al., 2014).

Wildlife and Marine Species

Several critical species such as larval and juvenile blue crabs, brown shrimp, southern flounder and red drum are found in Galveston Bay. Stocks are declining due to overfishing, loss of habitat and water pollution– threatening the vitality of the commercial fishing industry, which is a major component of the island's economy (TCRMP, 2023).

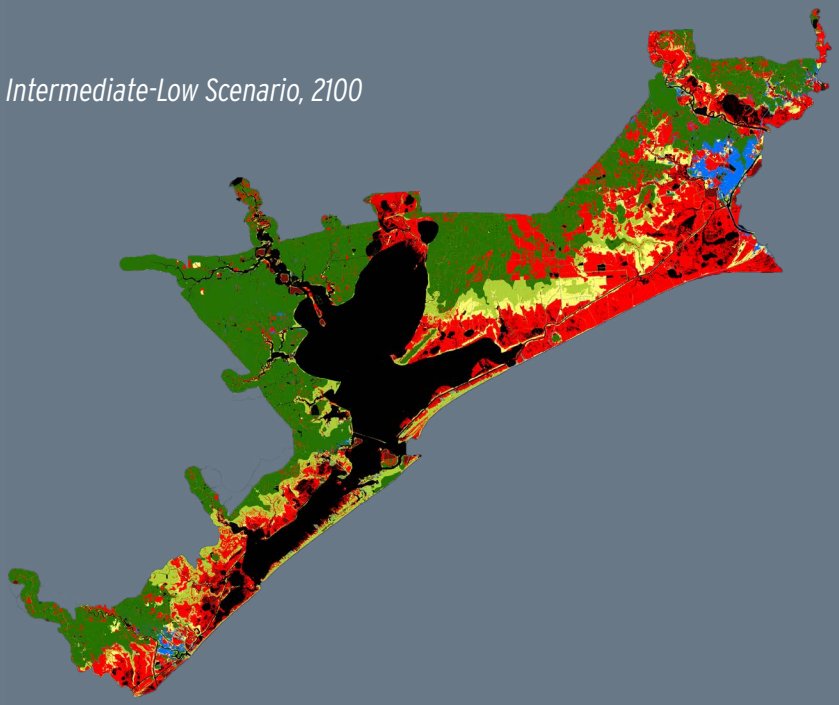
Droughts and hurricanes have devastated oyster populations in the bay (GBF and HARC, 2023). Oyster mortality rates increased from 11% before Hurricane Harvey to 48% post Harvey; the storm's extreme rainfall significantly lowered the salinity of Galveston Bay (Du et al. 2021). In the future, climate change may exacerbate many stressors on fish populations, including changes in ocean pH and salinity and an increase in water temperature. Galveston Bay's winter water temperature has increased more than 10% in the last 15 years causing the loss of plants and marine life in these systems that moved upwards into new areas.

The island is home to a variety of mammals (rabbits, raccoons, river otters), reptiles (rattlesnakes,

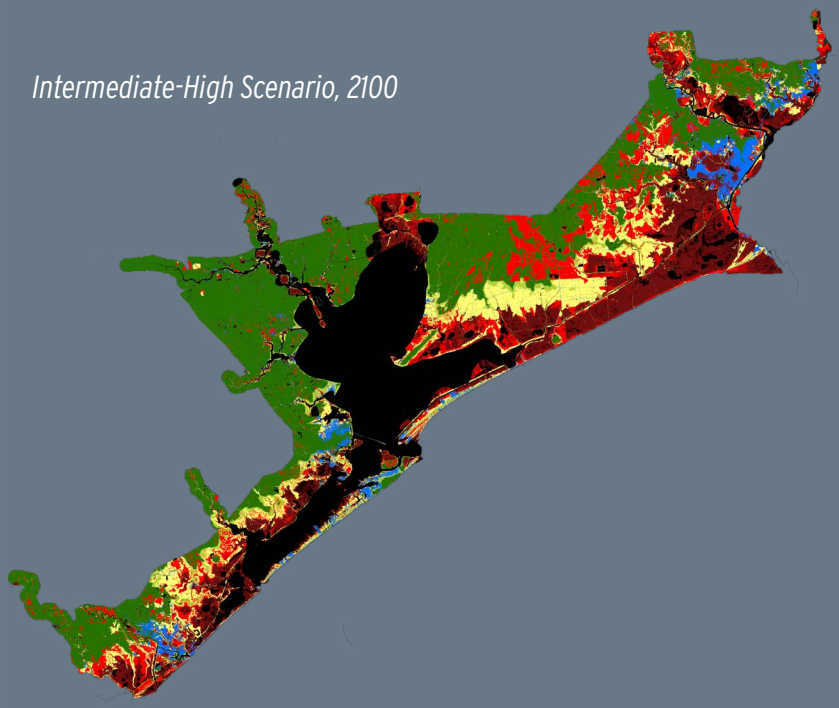
Figure 7. Geohazards Map

Developed by Harte Research Institute at Texas A&M University-Corpus Christi

Intermediate-Low Scenario, 2100



Intermediate-High Scenario, 2100



- EXTREME (historic storm washover channels, future open water)
- IMMINENT (present day critical environments such as wetlands, dunes, beaches)
- HIGH (at risk of becoming critical environments by 2100)
- MODERATE (not expected to become future critical environments; storm surge vulnerability > 0.5)
- LOW (not expected to become future critical environments; storm surge vulnerability < 0.5)
- FUTURE FLOODING (present day urban areas and roads expected to flood in 2100)

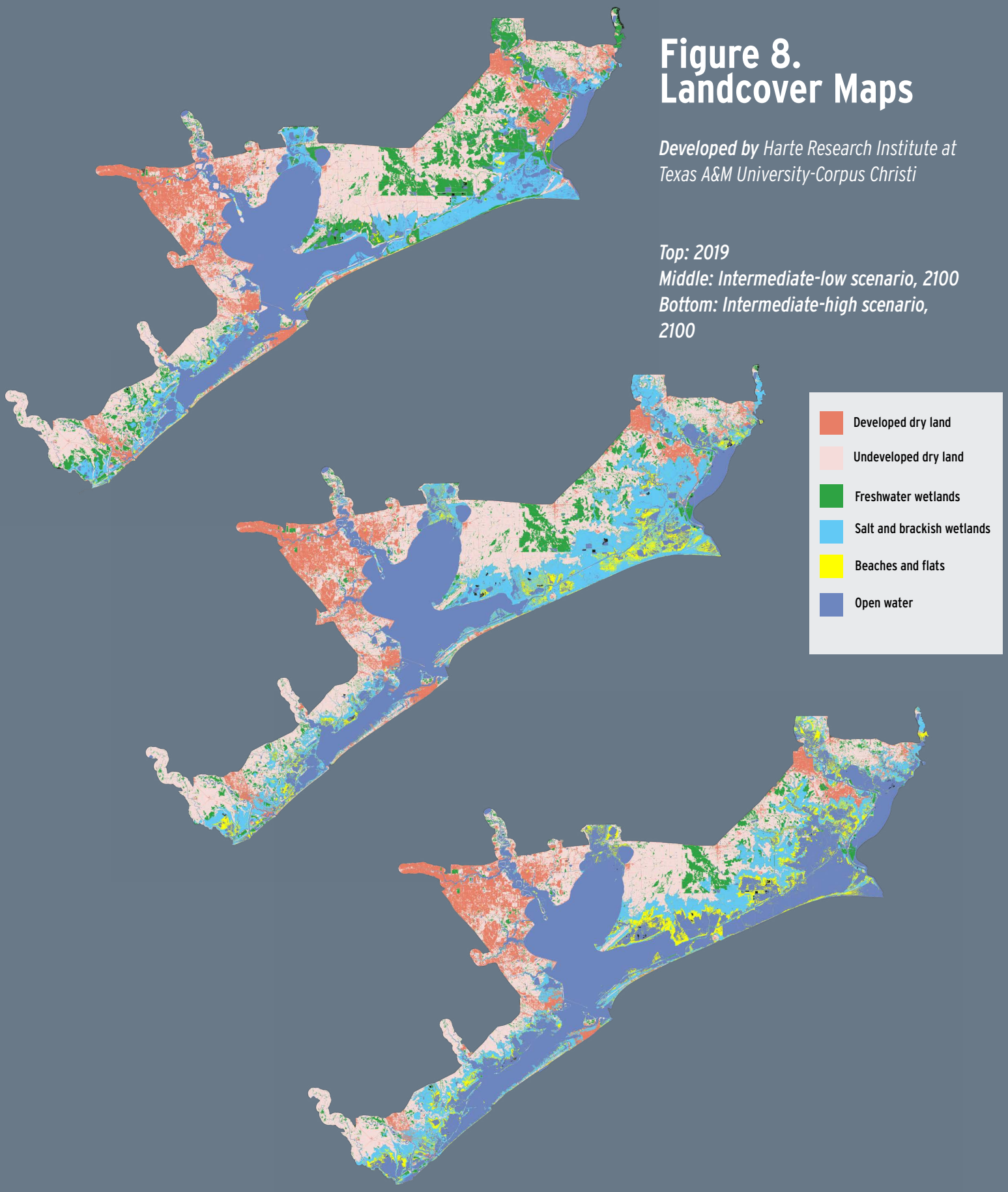


Figure 8. Landcover Maps

Developed by *Harte Research Institute at Texas A&M University-Corpus Christi*

Top: 2019
Middle: Intermediate-low scenario, 2100
Bottom: Intermediate-high scenario, 2100

Kemp's ridley sea turtle hatchling (National Parks Serivce)

cottonmouth, American alligator, king snakes, alligator snapping turtles), and birds (Roseate spoonbill, tri-colored heron, brown pelican) that depend on high-quality breeding and nesting habitats to thrive. Loss of coastal habitats will cause cascading impacts to the wildlife that thrive in these systems. Several studies conducted in the Galveston Bay Estuary found a link between a decline in wetland area and declining waterbird populations, including wetlands found on rookery islands (USFWS, 2021). An increase in the sand temperature on beaches also disrupts the breeding balance for sea turtles, leading to more female eggs at higher temperatures. (Patrício et al., 2021).

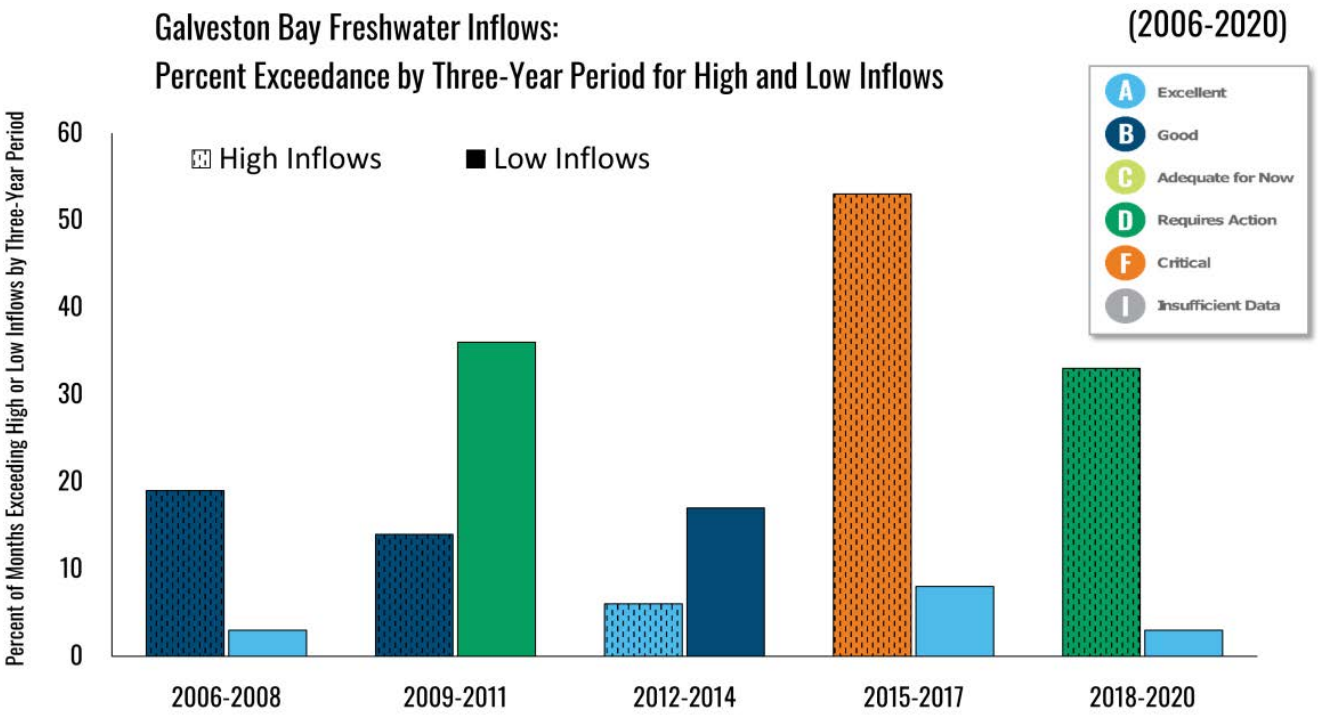
Water Quantity and Quality

Two major river sheds drain into Galveston Bay. The quality of freshwater from those watersheds influences the salinity, nutrient levels, and sediments found in Galveston Bay. High flow events caused by extreme rainfall and hurricanes as well as low flow events caused by drought and upstream water use are detrimental to the Bay's thriving biodiversity.

High flows bring more nutrients to the bay; this causes algal blooms that deplete oxygen levels and lower the salinity of the bay system. Symptoms of eutrophication are higher in Galveston Bay compared to other parts of the Texas Coast (Bugica et al., 2020). Other research found that fish kills, primarily caused by low dissolved oxygen levels, are more pronounced in Galveston Bay compared to other estuaries in Texas (Thronson and Quigg, 2008). High acidification due to low salinity and pH levels also impeded the recovery of oyster reefs post Hurricane Harvey (Hicks et al., 2022).

Extreme weather events can have long-lasting impacts on the Bay's health. According to the Galveston Bay Report Card, the bay is susceptible to alternating between both extreme flow events, experiencing more high flow events between the periods of 2015-2020 likely due to Hurricane Harvey and more low flow events between 2009-2014 due to the 2010-2013 Texas drought. As the climate continues to change, these extreme events such as hurricanes and drought will continue to intensify. For instance, increasing annual temperature will contribute to longer and prolonged droughts.

Figure 9. Galveston Bay Inflows

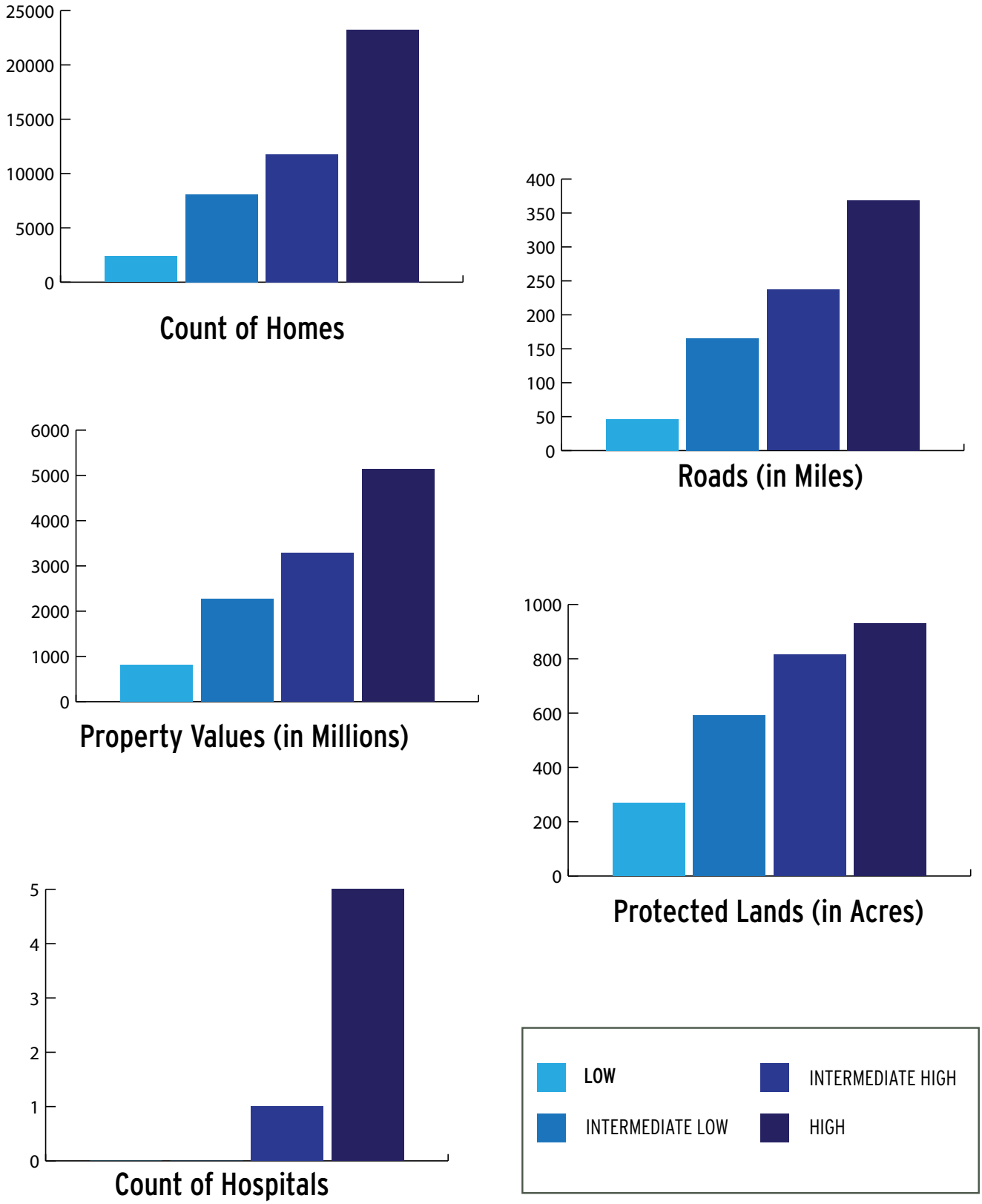


Built Environment

Sea level rise will result in the inundation of critical facilities and infrastructure along the coast. According to Climate Central's Risk Finder Tool that combines data from over ten federal agencies, roads, hospitals, and homes are at-risk in Galveston under intermediate low, intermediate and intermediate high sea level rise scenarios.

Figure 10 on the following page provides an overview of selected key variables from the Risk Finder Tool. Under the low sea level rise scenario, only 7.4% of the Island's homes are at risk; that number increases nearly 10 fold to 71.8% under the high sea level rise scenario. A high increase in sea level rise will also lead to property damages totaling $5.133 billion. Hospitals in the area are not at-risk under the low and intermediate low sea level rise scenarios but become susceptible under the intermediate high and high scenarios. The absence of these critical facilities and the essential services they provide will have far-reaching consequences on Galveston's functioning and future existence.

Figure 10. At-risk Critical Facilities Under Various Sea Level Rise Scenarios



Social Vulnerability

Galvestonians will experience climate risks differently based on their geographic locations and socio-economic factors. Understanding social vulnerability, or the susceptibility of different social groups to the adverse impacts of natural hazards, is critical to regional resilience planning. For example, older adult populations, refugee and immigrant communities, and renters face different challenges during a natural disaster; these factors may also increase their risks compared to other demographics. Figure 11 on page 34 displays the level of vulnerability according to FEMA's National Risk Index (NRI).

Communities on the east end of the island, from Jones Park to UT Medical Branch, were found to be highly vulnerable. This could be due to a higher than average socially vulnerable population in this area based on the demographic characteristics.

These socially vulnerable groups, often including the low-income minority populations living in lower-quality homes, are at greater risk of future hazards. Unequitable development patterns characterized by concentrated poverty and segregation separate these vulnerable groups in clusters and pockets across the island with limited access to information and resources to prepare for the potential climate-induced hazards. Even after a disaster strikes, these groups struggle to recover and rebuild due to lack of insurance and financial resources and trouble accessing federal funds. This unevenness in experiencing climate impacts and recovering to them makes certain population groups lag behind, hampering the overall community resilience of the island.

The table below (Table 4) provides a list of social vulnerability indicators in the four Galveston census tracts for which data is available (U.S. Department of Commerce, 2020). These include a higher than average number of people of color, high percentages of people without a high school degree, living in poverty, living in with rental units, disabilities and lack of health insurance.

Texas City Prairie Preserve (Courtesy of R.J. Hinkle for The Nature Conservancy in Texas)

Table 4. Social Vulnerability Indicators

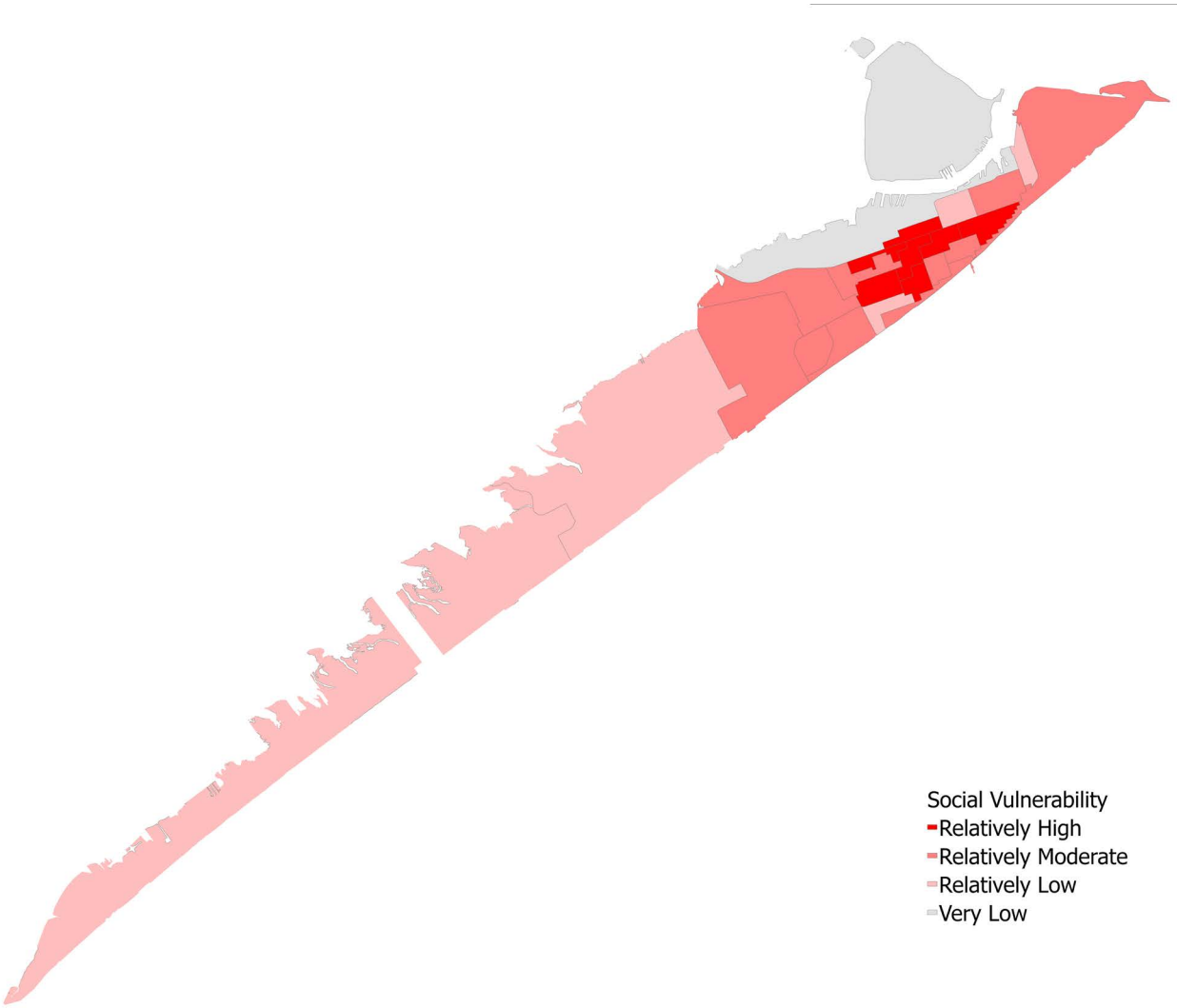
Social Vulnerability Indicators (2021)	Combined Tracts (%)	U.S. (%)
People under 5 years	4.9	5.9
People over 65 years	15.3	16
People of color (including Hispanic)	61.4	40.6
People who don't speak English well	6.1	4.1
People without a high school degree	18.8	11.1
Families in poverty	17.7	8.9
Housing units that are rentals	69.7	35.4
Households with no car	14.8	8.3
People with disabilities	18.2	12.6
People without health insurance	24.5	8.5

Data with coefficients of variation (CVs) between 12 & 40% are in red. These values have medium reliability and should be interpreted with caution.

Figure 11. Social Vulnerability Index

Source: FEMA

Social vulnerability is the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood. The rating below represent the relative level of a community's social vulnerability compared to all other communities in the country at the same level. A community's social vulnerability score measures its national rank or percentile.



NATURE-BASED CLIMATE ADAPTATION

Shoring up natural systems and maximizing ecological benefits can increase resilience across Galveston Island.

Natural Resources as Risk Reduction

Galveston Island is rich in wildlife and natural diversity, spanning wetlands, oysters, beaches and dunes, across the Gulf Coast and Galveston Bay, and the many fisheries and wildlife in between. These ecosystems and their wildlife benefit Galvestonians in many ways. Natural resources and ecosystems provide recreational opportunities, drive its tourism and fisheries-related economy, improve water quantity and quality, lower urban heat island effect, and benefit overall quality of life.

Natural resources also provide hazard risk reduction benefits; for example, marshes help to absorb wave impact, reducing storm surge and mitigating flood damages. These protective services and benefits may themselves be diminished by climate change over the next decade and beyond. Rising sea levels threaten to submerge the coastal marshes and dune systems. Warmer temperatures may create or exacerbate tree mortality and invasive species management challenges and increase ocean acidification.

Employing programs and adaptation strategies that protect natural resources and foster ecosystem and community resilience will help Galveston build a better approach for understanding and managing climate change. At the same time, nature based solutions offer a profound opportunity to enhance wildlife habitat. For example, a Kemp's Ridley Turtle nest—one of the most endangered species of sea turtles—was found on Babe's Beach in Galveston, a renourished beach that historically has not been a preferred nesting site for turtles.

The following section provides a discussion of adaptation strategies and resources that the Galveston community will likely want to consider when preparing for and responding to the effects of climate change.

Potential Adaptation Strategies

The framework for building traditional hard infrastructure projects is well established: most community stakeholders and technical experts are familiar with these types of flood mitigation solutions and the regulatory approval process they require.

Nature-based solutions, on the other hand, face barriers due to the lack of equivalent familiarity. Community members and stakeholders may lack technical training on the topic and express concerns about the effectiveness of such projects, hindering public support. Combined with a lack of regulations in place, nature-based solutions are often harder to adopt and implement.

Providing community members with concrete examples of successful and transformative adaptation projects can be a source of inspiration for designing new nature-based solutions. Additionally, a key strategy for promoting such projects will be identifying projects that enhance climate and community resilience for Galvestonians. For example, Galveston Bay Foundation's Sweetwater Nature Preserve is a 449-acre preserve located on the island where construction of an oyster shell breakwater is helping prevent coastal erosion. Another relevant example is the sustainable oyster reef restoration in Upper Galveston Bay, managed by the Nature Conservancy. The project aims to restore 40 acres of degraded oyster reef habitat, creating one of the largest oyster sanctuaries on the Texas coast.

Pushing the needle forward on similar projects in the future will require creating conducive social, policy, and legal environments for projects to move forward and become the preferred choices within communities. This includes building community capacity and cohesion, encouraging social acceptance, and ensuring long-term maintenance of these projects, supporting jobs and training programs, and influencing the local policy landscape.

Below, we identify four key pillars that can support the advancement of nature-based solutions and build overall community resilience. These pillars encompass a mix of specific strategies from existing planning efforts in Galveston and examples from other leading coastal planning efforts. Some Galveston-specific plans include the Comprehensive Plan, Hazard Mitigation Plan, West Galveston Island Greenprint for Growth, and Vision Galveston's Plan. While these plans include a plethora of nature-based solutions, these strategies are not always easily accessible among leading agencies and at times, are not complementary to each other. This report attempts to collate the recommendations related to nature-based solutions in Galveston. We also pull examples from other coastal states such as Hawaii's Coastal Adaptation Strategies and Maryland Climate Adaptation and Resilience Framework as well as general coastal adaptation strategies developed from EcoAdapt, National Wildlife Federation, and National Park Service to inform these strategies. Each strategy includes key actions most relevant to Galveston's social, economic, and ecological contexts.

Four key pillars to advancing nature and natural-based projects:

- **Identifying and implementing on-the-ground projects**
- **Building community capacity and cohesion to advance these projects**
- **Supporting climate jobs and training**
- **Fostering a conducive regulatory and policy landscape**

Pillar 1: Identifying and implementing on-the-ground projects

Protect, conserve, connect and restore terrestrial and aquatic habitats and manage species to support biodiversity, ecosystem services, and outdoor recreation during climatic changes.

1.1 Use living shorelines to stabilize shoreline edges, where appropriate

- Determine the living shoreline technique most suitable for a specific site using the Galveston Bay Shoreline Protection Model and identify steps needed to design, permit, and construct.
- Develop and implement improvements for priority sites (i.e. Seawall Beach and Seawolf Park) including, but not limited to, design and construction of offshore breakwater to protect against future events.

1.2 Explore construction of offshore oyster reefs and beds to attenuate wave energy, reduce erosion, and improve water quality

- Identify locations to implement oyster reef restoration projects. Reef cover is found to be abundant in West Bay and smaller in Jones Bay and Chocolate Bay.

- Scale and replicate successful restoration projects such as the sustainable oyster reef sanctuary in Upper Galveston Bay/Trinity Bay area, and community-driven oyster reef restoration in Mobile Bay, Alabama that provided jobs and training for fishermen who lost their livelihood due to the oil spill.

1.3 Protect and restore barrier beaches and dunes through renourishment and revegetation

- Investigate potential sand sources, such as northeast of San Luis Pass and off-shore.
- Develop and implement preservation activities for Babe's Beach, Seawall Urban Park and Dellanera Beach including, but not limited to, regular and strategic sand placement.
- Collaborate with existing organizations such as Galveston Park Board and Artist Boat working to renourish the Historic Seawall beaches and dune restoration from Stewart Beach to Surfside.

1.4 Restore degraded salt marshes and facilitate marsh migration

- Favor restoration projects along the Island's northern shoreline that offer the greatest potential to improve the bay ecosystem. Develop a layer within Galveston's GIS to coordinate with Galveston Bay Estuary Program and other conservation partners to identify, in advance, potential mitigation sites on the island.
- Limit further development along marsh edges to reduce impacts of sea level rise and facilitate inward marsh migration.

1.5 Consider opportunities to establish habitat connectivity on and around local project sites

- Manage non-protected and/or mixed-use areas between protected landscape zones to facilitate habitat and species movement. Develop and implement streetscape improvements along 27th Street, between Seawall, McGuire, Dent Recreation Center, Menard Park, Kempner Park, Kermit Courville Stadium, and Broadway to increase the natural canopy.
- Combine dense mixed-use development with green space in East End Flats; turn large road right-of-ways, alleys and vacant lots into a green infrastructure network.

1.6 Implement site-specific green infrastructure measures to mitigate stormwater runoff, reduce urban heat island effect, and improve water quality

- Fund, design, and construct a pilot rain garden, pollinator garden, or pocket prairie in the heart of North of Broadway and engage community members to both educate them on the function of the feature and gather feedback on future design.
- Improve urban tree canopy through native tree plantation, preservation, and reforestation along the City's most important corridors, such as Broadway and 25th Street, the West End, and the Urban Core.

1.7 Prioritize low-impact development (LID) practices and conserve land to increase open space

- Upgrade downtown pedestrian sidewalks with low-impact development measures including, but not limited to, bioswales, permeable pavements, infiltration planters.
- Redesign parks, such as Jones Park, Shield Park, Crockett Park,, Spoor Field, and Pocket Park, are faced to mitigate flooding issues, while still providing enjoyable, usable space for the surrounding

community.

- Implement West Galveston Island Greenprint for Growth Plan that identified 6,835 acres of the existing natural areas on the West End with high conservation values.
- Conserve land to increase open space.

1.8 Sustain freshwater inflows

- Encourage public and Galveston Bay Estuary Program stakeholder participation in regional water planning groups and the development of priority policies that ensure adequate quantities of freshwater reach Galveston Bay.
- Develop or support outreach initiatives that promote water conservation and educate the public on the value and importance of freshwater inflows.

Pillar 2: Building community capacity and cohesion to advance projects

Empower all communities to equitably aid in the adaptation of our natural resources by including them in the protection and conservation process so that they have a vested interest in safeguarding natural resources in a changing climate.

2.1 Develop strategies for enhanced outreach and education

- Embed outreach strategies in all planning processes (plan development, implementation, updates) for the City's Comprehensive Plan, Hazard Mitigation Plan, etc.
- Include outreach components in natural infrastructure projects such as dune restoration, living shoreline design so that residents and visitors understand and support why the work is occurring.

2.2 Empower grassroot champions to co-design nature-based projects

- Identify and connect key community leaders and stakeholders who lead the discourse on climate change and equitable resilience planning in the city.
- Create a community-of-practice with these community champions to discuss, share and transfer opportunities related to nature-based projects.

2.3 Create a city-community liaison to align city leadership, non-profits, and philanthropic interests to enhance collaboration and coordination

- Engage the local philanthropic community to potentially fund the liaison position, and support conservation groups such as Galveston Bay Foundation, Artist Boat, Houston Audubon, Turtle Island Restoration Network, as well as the City of Galveston.

2.4 Coordinate with existing organizations to promote ecotourism

- Collaborate with Galveston Island Nature Tourism Council, Artist Boat, the Galveston Bay Foundation, Audubon, Turtle Island Restoration Network, Moody Gardens, Vision Galveston, City of Galveston and the Galveston Park Board, which all manage diverse ecotourism programs, events, and education

campaigns to work toward a coordinated plan.

Pillar 3: Supporting climate jobs and training

Improve climate training, invest in climate-related or climate-enhanced jobs, and create connections with higher-education networks.

3.1 Support and develop opportunities for community science

- Encourage participation in water monitoring, clean ups, and stormwater programs and practices.
- Develop partnerships to equitably deliver training related to nature-based solutions for diverse communities.

3.2 Launch a place-based resilience training program for city officials

- Organize programs to provide knowledge and training necessary to design and develop nature-based solutions (i.e., Louisiana's Working With Nature Training).
- Invite trainers from existing programs such as NOAA's Adaptation Planning for Coastal Communities to conduct hands-on, tailored sessions with Galveston officials.

3.3 Implement project and place-based learning through existing collaborations and frameworks

- Collaborate between established environmental education organizations, such as Artist Boat, educational institutions like TAMU's Institute for a Disaster Resilient Texas and Galveston ISD, and government departments to develop a comprehensive environmental education approach.
- Implement National Wildlife Federation's Resilient Schools Consortium Program with local partners to increase risk and resilience awareness in high schools.

Sweetwater Nature Preserve (Courtesy of Galveston Bay Foundation)

3.4 Encourage backyard habitat development practices

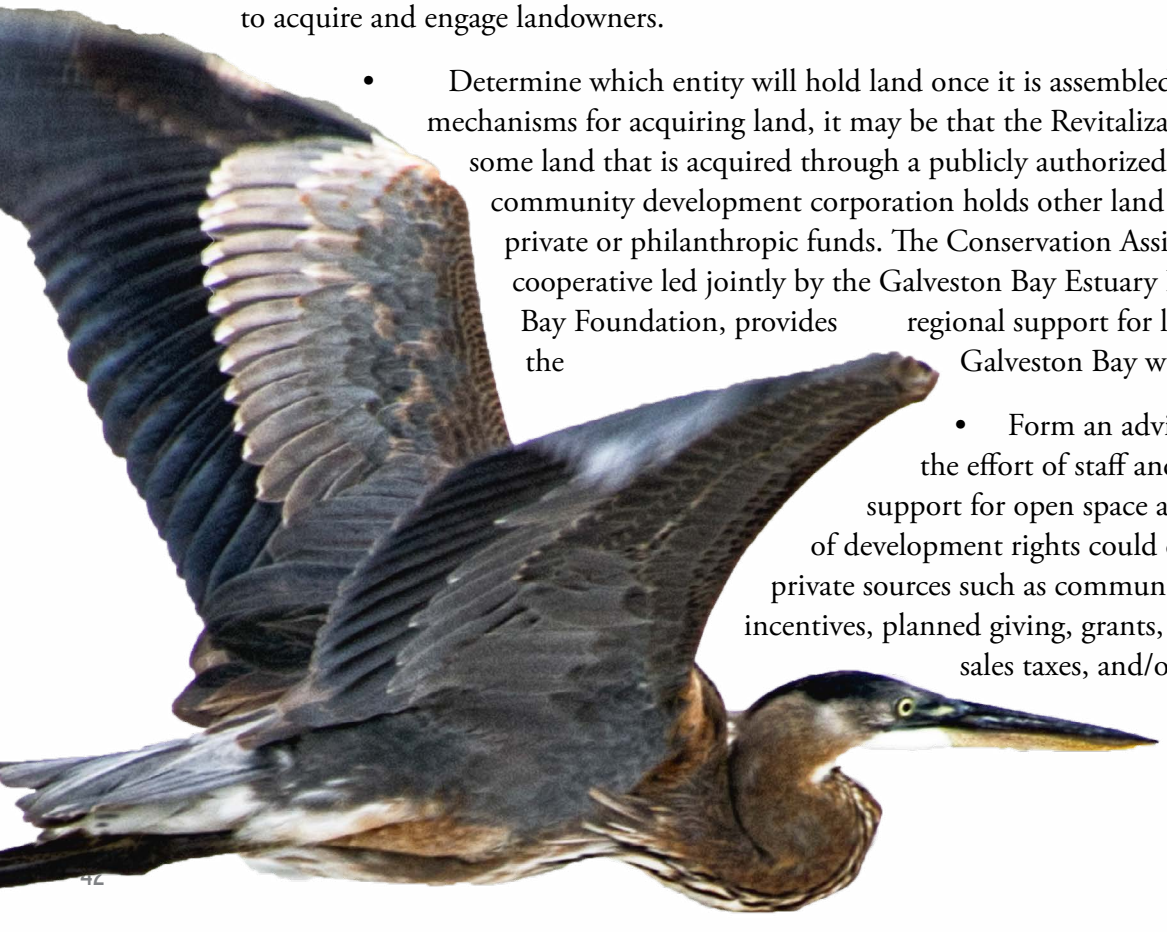
- Increase public awareness of the benefits of using native or naturalized, non-invasive plants.
- Promote participation in programs such as the National Wildlife Federation's Certified Wildlife Habitat™ program that helps transform a backyard, school, business or community into safe and healthy haven for local wildlife.
- Encourage participation in the Texas Wildscapes certification program offered by Texas Parks and Wildlife Department that offers advice on planting and maintaining native vegetation, creating water sources such as birdbaths and ponds, and other actions designed to create places for birds, small mammals, and other wildlife to feed and drink, escape from predators, and raise their young.

Pillar 4: Fostering a conducive regulatory and policy landscape

Ensure that all parties and partners involved in implementing adaptation-focused natural resource and ecosystem management goals have a clear understanding of priorities, responsibilities and roles, and seek to eliminate barriers and obstacles.

4.1 Conserve land and use financial incentives to remove infrastructure from floodplains

- Acquire properties with high natural resources value (e.g., climate refugia, future or priority habitat, migration corridors). Support and enhance land acquisition/dedication (e.g., existing efforts by Artist Boat) to protect land in perpetuity with deeds for conservation, with a minimal footprint (<2% in conserved areas) for "improvements" or built infrastructure. Additionally, there is an effort underway to create the Lone Star Coastal National Recreation Area with a coalition of local supporters, focusing on voluntary participation from landowners and minimal federal funding. Identify key land to acquire and engage landowners.
- Determine which entity will hold land once it is assembled. Given the different mechanisms for acquiring land, it may be that the Revitalization Authority holds some land that is acquired through a publicly authorized land bank, while a community development corporation holds other land that is acquired through private or philanthropic funds. The Conservation Assistance Program (CAP), a cooperative led jointly by the Galveston Bay Estuary Program and Galveston Bay Foundation, provides regional support for land conservation within the Galveston Bay watershed.
- Form an advisory committee to guide the effort of staff and volunteers. Local support for open space acquisition and purchase of development rights could come from public and private sources such as community benefits' development incentives, planned giving, grants, general obligation bonds, sales taxes, and/or other dedicated taxes.



Great Blue Heron

Ideally, the City of Galveston should continue to encourage public-private partnerships to maximize open space. Bonds are desirable as they offer a method of long-term funding. A less costly alternative would be to include open space acquisition as an expense item in the annual budget, although this option requires annual reauthorization and does not constitute a clear commitment to the program.

- Purchase development rights, also known as a conservation easement. Usually a land trust (e.g., Artist Boat), or another organization linked to the local government, offers to buy development rights on a parcel. Since the program will be voluntary, the property owner may choose to accept, refuse or negotiate price. If an agreement is made, a permanent deed restriction is placed on the property, limiting the types of activities that may take place on the land.
- Utilize CEPRA funding to receive grant funds for acquisition of properties that are wholly or partially on the public beach easement. This will not only provide additional opportunities for open space but also allow for large-scale restoration of dunes and beach renourishment projects. However, development of this type of a beachfront acquisition program may prove controversial and funding may prove to be very competitive.

4.2 Update building codes to account for climate change impacts.

- Undertake a review and assessment of the current adopted building codes (including the City's flood damage prevention ordinance) and enforcement policies and practices to account for climate change impacts.
- Identify areas that could be strengthened or improved, including requesting an ISO Building Code Effectiveness Grading Schedule (BCEGS).

4.3 Incorporate the best available science on the impacts of climate change in policies, regulations and programs

- Update comprehensive plan, floodplain management regulations, setbacks and buffers for present and future climate-related risks and development.
- Consider adoption and enforcement of freeboard requirements into the City's Flood Damage Prevention Ordinance.
- Advocate for the State of Texas to require insurance companies to provide windstorm coverage with all homeowners' insurance policies where such coverage is required or indicated, while acting as a reinsurer to reduce insurance companies' risk.

4.4 Create local wetlands protection bylaws and regulations

- Maintain policies that avoid or minimize impacts to island wetlands.
- Strengthen or revise the existing excavation ordinance to encourage mitigation to occur within the drainage basin or within the same, or neighboring, watersheds.
- Consider a minimum 50 foot buffer area for all wetlands. Create incentives for greater setbacks. Prohibit the placement of impervious surfaces and septic systems in buffers but create allowances for other uses, such as landscaping, fencing, and recreational areas.

4.5 Designate areas requiring special protection in light of climate change (e.g., beaches, wetlands, priority habitat) and limit new development in these areas

- Identify priority sites for protection or acquisition, considering the following: existing level of protection (public lands and lands with perpetual conservation easements); level of significance and threat; and potential to serve multiple functions—resource protection, passive recreation, view protection, etc.

4.6 Use transferable development credits to reduce risky coastal development

- Transfer of Development Rights are provided for in ordinances that allow property owners to transfer development rights from one location to another, and can be used as an incentive to redirect development away from vulnerable areas. The most controversial aspect of this type of program is the selection of receiving areas that will be subject to increased development densities. Community acceptance of this strategy will require public outreach and education. Local land trusts will likely be valuable collaborators in developing such programs.

- Purchase of Development Rights through conservation easements is commonly used to preserve open space and farmland and entails local governments and nonprofits purchasing development rights so that the land remains under private ownership. By purchasing the development rights for vulnerable properties rather than the land itself, future development is restricted while allowing the property to be used for less intensive uses and preventing development in areas needed for habitat migration and to encourage development elsewhere.

4.7 Implement comprehensive water resources management such as One Water

- Engage citizens to work with the City of Galveston to advocate for an integrated approach to water supply planning. Water supply management decisions can impact natural resources; therefore, water resource management decisions should attempt to incorporate multiple benefits and follow a One Water planning process.

- Share resources and case studies of other cities that have implemented One Water, demonstrating multiple benefits and positive outcomes for resilient water supply (e.g., Austin, Los Angeles, Denver).

4.8 Create incentives for integrating nature in development

- Continue to engage West End stakeholders, including owners of large undeveloped tracts, in discussions regarding goals for West End conservation and development and consider creation of incentives for development projects. Incentives and regulations can include but are not limited to: density bonuses, transfer of development rights (TDR), purchase of development rights (PDR), easements, cluster zoning, and wetlands or habitat preservation ordinances.

4.9 Increase collaboration among local, regional, and state entities

- Join regional and global networks addressing climate change responsiveness such as C40.

- Coordinate with local organizations such as Galveston Island Tree Conservancy and participate in national programs such as "Tree City" to help build support for the importance of the City's tree canopy.

Texas City Prairie Preserve (Courtesy of R.J. Hinkle for The Nature Conservancy in Texas)

Funding Opportunities

In order to contend with climate risks such as sea level rise and stronger hurricanes, as well as rapid growth and development, Galveston needs to invest in and prioritize nature-based solutions. There is no dearth of well-intentioned plans and projects in Galveston right now. For example, the Texas Coastal Resiliency Master Plan identifies several nature-based strategies recommended in this assessment, including, beach nourishment on the West End beyond the terminus of the Seawall (estimated project cost: $31,000,000) and West Galveston Seawall to 13 Mile Road (estimated project cost: $12,600,000); wetland acquisition (estimated project cost: $15,600,000); and oyster restoration in Jones Bay (estimated project cost: $3,200,000). Existing plans and projects such as the Galveston Bay Plan (2018) and the Galveston Island Ecosystem Restoration from the Gulf to the Bay project in the Long-Term Community Recovery Plan are also designed to achieve large-scale habitat restoration of dunes, saltwater marshes, seagrass beds, and oyster reefs in Galveston.

Moving these projects from planning to implementation will require resources—time, expertise, and most importantly, a dedicated and continuous stream of investments.

The two most significant vehicles for these investments are funding and financing. Funding mechanisms include grants and donations provided by federal, state, and philanthropic sources (e.g., USDA Urban and Community Forestry Program, NFWF Coastal Resilience Fund) to provide a one-time cost of specific nature-based projects—and the money is not repaid by the recipient. Some of these programs have match requirements, though they may waive or reduce those requirements for economically-disadvantaged

communities. Financing mechanisms such as loans (e.g., Clean Water State Revolving Funds) and bonds (e.g., General Obligation Bond in Miami, Florida, Environmental Impact Bonds) can provide the needed supplementary project funds. However, they require repayment and interest for their use, however often certain portions of these funds can be available as forgivable loans.

Following the Deepwater Horizon Oil Spill disaster, the RESTORE Act, the Gulf Environmental Benefit Fund administered by the National Fish and Wildlife Foundation, and the Natural Resource Damage Assessment are providing billions of dollars to protect and restore damaged coastal habitats in the Gulf. Further, the United States Army Corps of Engineers (USACE) has an estimated $57 billion dollar plan titled the Coastal Texas Study or "Ike Dike" that incorporates Coastal Storm Surge Reduction Measures (CSRM) and Ecosystem Restoration (ER) components. However, while numerous ecosystem restoration measures are found further down the Texas coast, the Upper Texas Coast, which includes Galveston Island, does not contain any of these components. As this project moves forward, there might be opportunities for design changes that could potentially integrate nature-based solutions.

Several federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), U.S. Department of Interior (. DOI), Federal Emergency Management Agency (FEMA), and U.S. Department of Housing and Urban Development (HUD) provide competitive grants that allow communities to develop NbS projects and seek technical assistance. When leveraging these federal funding opportunities, communities and practitioners benefit from outside-of-the-box thinking (FEMA 2021a). For example, shoreline stabilization projects such as living shorelines and wetland restoration are eligible for grants through the U.S. Fish and Wildlife Service Coastal Program, NOAA Community-based Restoration Program, and U.S. EPA Clean Water Act Nonpoint Source Grants. They are also eligible for FEMA hazard mitigation program funding, as well as for a new surface transportation resilience grant program (PROTECT grants), authorized by the Infrastructure Investment and Jobs Act. This means that multiple co-benefits provided by NbS make them eligible for a wide variety of grant opportunities, some of which may be less obvious than others.

Several state programs are increasingly being leveraged for nature-based opportunities that can be easier to navigate and less competitive than federal funding opportunities. Funds are administered through the Texas General Land Office, Texas Water Development Board, and Texas Department of Emergency Management.

- Gulf of Mexico Energy Security Act (BOEM/GLO): Coastal projects targeting the restoration of coastal damage from Hurricanes Ike and Harvey and enhancing resiliency of the Texas shoreline to prevent future threats
- Flood Infrastructure Fund (FIF) (TWDB): Flood control, flood mitigation, and drainage projects, including nature-based approaches
- Texas Coastal Management Program (CMP) (NOAA/GLO): Coastal natural hazards response, critical areas enhancement, and ecotourism development
- Coastal Erosion Planning and Response Act (CEPRA) (GLO): Coastal erosion response projects and related studies to reduce the effects of and to understand the processes of coastal erosion

Private investments made through grants from nonprofits (National Fish and Wildlife Foundation), and philanthropic entities can also complement public funding.

Community-led initiatives such as crowd-funding can fund a portion of a NbS project while improving a

Table 5. Examples of Funding and Financial Mechanisms

Source	Mechanism	Type	Examples
Public	Federal grants	Funding	Community-based Restoration Program (National Oceanic and Atmospheric Administration); Building Resilient Infrastructure and Communities (BRIC) Grant Program (Federal Emergency Management Agency); Coastal Program (U.S. Fish and Wildlife Service; Readiness and Environmental Protection Integration (REPI) Program (U.S. Department of Defense)
Public	State grants	Funding	Texas Coastal Management Program (NOAA/Texas General Land Office); Resiliency through Restoration Initiative (Maryland Department of Natural Resources; Outdoor Equity Grants Program (California Department of Parks and Recreation)
Public	Loans	Financing	Clean Water State Revolving Fund (U.S. Environmental Protection Agency)
Private	Environmental impact bonds	Financing	Environmental Impact Bond (Quantified Ventures)
Private	Disaster insurance	Financing	California Wildfire Resilience Insurance (The Nature Conservancy)
Public-Private	Competitive grants	Funding	National Coastal Resilience Fund (National Fish and Wildlife Foundation)
Public-Private	Blended Finance	Finacing	Nature+ Accelerator Fund (International Union for Conservation of Nature, Mirova Natural Capital, and the Global Environment Facility)
Community-led	Crowdfunding programs	Funding	In Our Backyards New York City
Community-led	Community grant programs	Funding	Portland Clean Energy Community Benefits Fund

community's social fabric by bringing local volunteers, non-profit groups, and donors together.

On the previous page, we provide a list of different funding opportunities that have supported NbS projects across the country (Table 5). The list, while not exhaustive, can help Galveston learn from its peers and leverage new funding opportunities to implement plans and projects on the island.

Innovative funding opportunities that the City can investigate for NbS projects include:

- Development impact fees dedicated to land acquisition and nature-based projects
- Beach user fees, including parking fees from Seawall Boulevard (e.g., the Galveston Park Board collects and directs revenue, in addition to hotel occupancy tax fees which must be used to promote tourism and convention/hotel industries including beaches).
- Convention Center overflow funds
- Industrial Development Corp funds that can be used to acquire lands for parks
- Awards and certifications

Tools and Resources

The wide range and complexity of tools for coastal climate adaptation can be overwhelming. Table 5 on the following page provides an overview of available tools.

American Oystercatcher

Table 6. Examples of Tools Available for Coastal Resilience and Adaptation Planning

Tool	Agency or Organization	Summary	Models	Case Studies	Data	Tools	Training and Collaborations
Galveston Bay Shoreline Protection Model	Galveston Bay Foundation	Offers conditions and associated shoreline protection recommendations at any location along the Galveston Bay shoreline.	Yes			Yes	
Galveston Bay Atlas Map	Texas A&M Institute for a Disaster Resilient Texas	Provides a comprehensive suite of geospatial variables including built environment, natural features, hazard events, etc.				Yes	
Design Guides for Nature-based Approaches	Texas General Land Office	Offers design, permitting, planning and construction, and monitoring guidance.			Yes		Yes
Mapping Intertidal Oyster Reef in Galveston Bay	Galveston Bay Estuary Program	Provides the spatial extent of intertidal reefs in west Galveston Bay and a current estimation of the standing stock of intertidal oysters in Galveston Bay.		Yes	Yes		
Coastal Restoration Toolkit	Restore America's Estuaries	Includes various mapping tools for identifying and evaluating adaptation options.				Yes	
National Climate Assessment Texas State Summary	US Global Change Research Program	Provides an integrated assessment of observed and projected climate changes and key impacts.		Yes	Yes		
Digital Coast	NOAA	Offers data, tools, training, and stories from the field on coastal issues	Yes	Yes	Yes	Yes	Yes

CONCLUSION

5

Next Steps and Future Action

Climate change is already causing repercussions for Galveston's communities, wildlife and natural habitats. Building resilience to future climatic events will require commitment from leadership, engagement from key stakeholders, and technical and funding support from government agencies and philanthropy. Equipped with a thorough understanding of climate risks, all stakeholders have a role to play in applying the strategies identified in this assessment to their work. The accelerating pace of climate change calls for bold, urgent, and innovative strategies with co-benefits for boosting ecosystem services, enhancing recreation, and supporting tourism. Yet, time, money, and resources are limited. This section explores next steps and considerations to support the implementation of nature-based solutions in the region.

To understand the key priorities for community stakeholders in Galveston, we conducted a stakeholder roundtable with 12 individuals from non-profit, city of Galveston, academia and philanthropy. Additionally, the project team conducted a field trip with Artist Boat to learn about their coastal land preservation and education efforts. Several barriers to advancing nature-based solutions were identified, such as distrust in city or county government based on historical promises, status quo mindset, siloed decision making, and lack of education and funding structures for city council and enforcement of building codes.

The individuals from following entities participated in the roundtable:

- Bayou Preservation Association
- City of Galveston
- Galveston Bay Foundation
- Galveston Tree Conservancy
- Harris and Eliza Kempner Fund
- Texas A&M Agrilife
- Turtle Island Restoration Network
- University of Texas Medical Branch
- Vision Galveston

Creating enabling conditions through authentic collaboration, listening, and trust-building are long-term strategies to pave the way for effective climate adaptation on the island.

The suggested strategies in this assessment will still require prioritization to ensure continuous funding and momentum is maintained. The roundtable stakeholders identified the following as top priorities for advancing nature-based solutions:

- Pillar 1: 1.1. Use living shorelines to stabilize shoreline edges, where appropriate
- Pillar 2: 2.3. Create a city-community liaison to align city leadership, non-profits, and philanthropic interests to enhance collaboration and coordination
- Pillar 3: 3.3. Implement project and place-based learning through existing collaborations and frameworks
- Pillar 4: 4.4. Create local wetlands protection bylaws and regulations

Key Considerations for Implementation

The National Wildlife Federation, through our work on climate adaptation and resilience, has identified the following seven "key considerations" for communities to use in the design and application of nature-based solutions (Pathak et al., 2022). The key considerations can help support the development and implementation of the top priorities identified by the stakeholders.

- Recognize natural systems and processes as critical infrastructure. This should include natural systems that provide essential ecosystem services including protective benefits from hazards, such as flooding, erosion, stormwater, and extreme heat. Recognize, too, the non-material value (e.g., cultural, aesthetic, spiritual) of biodiversity and natural ecosystems.
- Consider climate impacts on priority natural assets. Ecosystems are themselves being affected by changing climatic conditions, and those vulnerabilities and risks should be understood and addressed in community-based adaptation and resilience planning.
- Consider equity implications in the design and application of nature-based solutions. To avoid unintentional consequences, such as displacement of disadvantaged communities, nature-based solutions should be planned and implemented with the engagement of local stakeholders and residents.
- Ensure that nature-based solutions yield net positive biodiversity benefits. Nature-based solutions should not only provide protective value to communities, but should also yield net biodiversity benefits, for instance through using regionally appropriate designs and materials (e.g., native plants).
- Seek to protect or restore critical natural infrastructure. This can involve protection of still intact natural systems, restoration of degraded systems, use of nature-based designs in engineered systems, and/or integration of natural (green) and engineered (gray) approaches in hybrid infrastructure.
- Give natural features and processes space to function. Consider how and where climate change may increase community exposures to potentially hazardous natural processes. Don't create new hazards or exacerbate existing risks through inappropriate siting of new development and infrastructure, and consider where—and when—existing infrastructure may need decommissioning or relocation.
- Integrate nature-based solutions into existing planning processes. Mainstreaming nature-based solutions into existing programs, policies, and planning processes can facilitate adoption, successful implementation, and funding of these approaches.

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NATIONAL WILDLIFE FEDERATION

Texas Coast and Water Program
505 E. Huntland Dr., Suite 530, Austin, Texas 78752

Jennifer Walker, Director · walkerj@nwf.org · 512.610.7776

Arsum Pathak, Senior Adaptation and Coastal Resilience Specialist
pathaka@nwf.org · 512.610.7787