# VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

## An Assessment for the Texas Mid-Coast

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**Texas Coast and Water Program**

**Suggested Citation:** Pathak, A., & Fuller, A. (2021). *Vulnerability and Adaptation to Climate Change: An Assessment for the Texas Mid-Coast*. Austin, TX: National Wildlife Federation.

**Acknowledgements:** The National Wildlife Federation would like to thank the Cynthia and George Mitchell Foundation for their financial support that made this work possible. We would also like to thank the following expert reviewers who provided comments and suggestions that helped improve this report: Dr. David Yoskowitz and Dr. Kateryna (Katya) Wowk (Harte Research Institute, Texas A&M University-Corpus Christi) and Myron Hess (Tributary Consulting). We thank Jonathan Seefeldt for the final design and layout of this work.

**Cover image:** A whooping crane in the Aransas National Wildlife Refuge along the Texas Mid-Coast. Photo by Kaila Drayton, National Wildlife Federation.

*All photos unless otherwise noted are by Kaila Drayton, National Wildlife Federation.*

**National Wildlife Federation**
**Texas Coast and Water Program**

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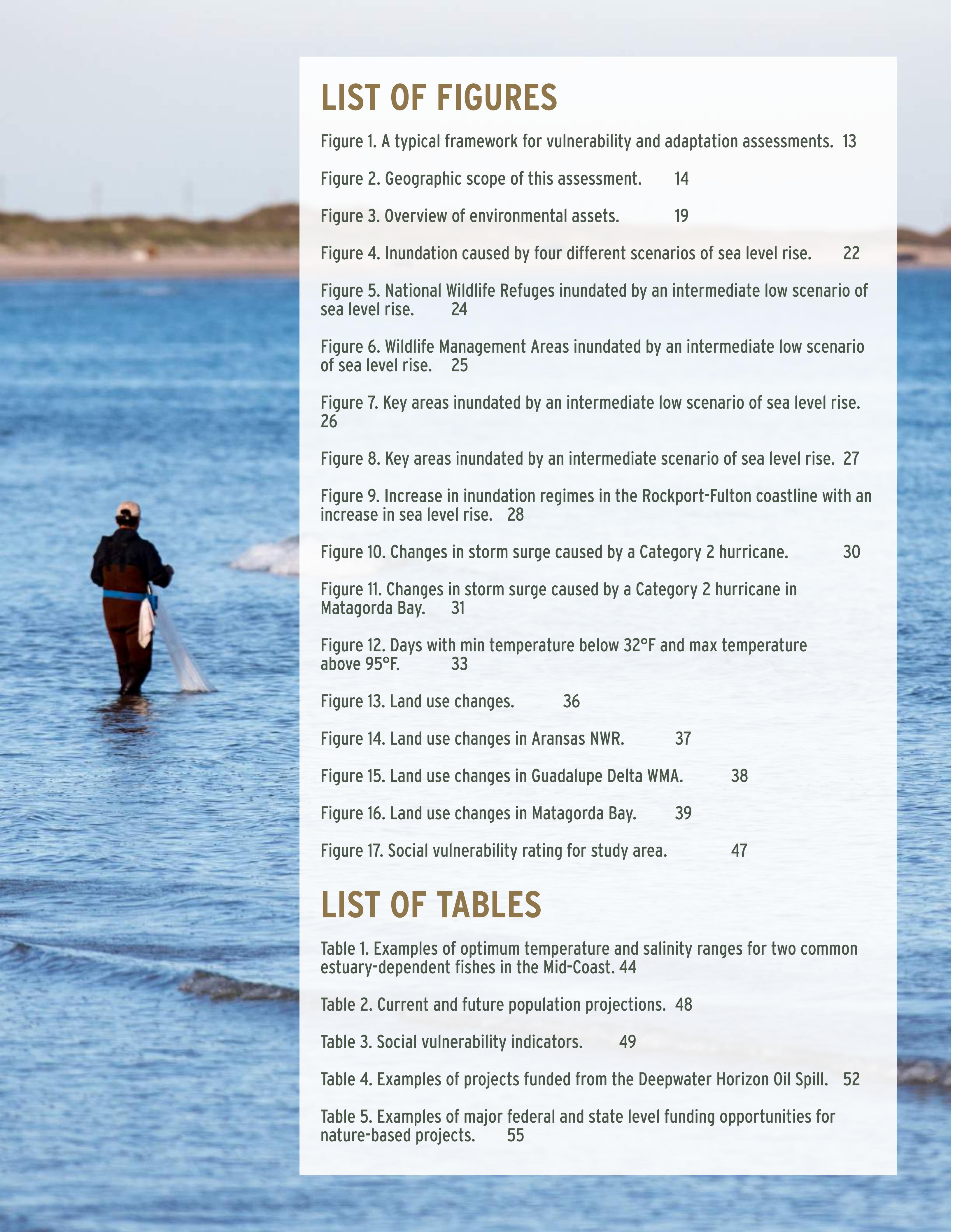

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# EXECUTIVE SUMMARY

**In a time of increasing climate variability, local leaders and decision-makers in the Mid-Coast need to account for emerging environmental, social, and economic impacts.**

The purpose of this assessment is to equip local leaders and decision-makers in the Texas Mid-Coast with locally relevant information about the area's future related to climate change impacts, enabling them to make greater investments in natural assets to shore up coastal environments for wildlife, local economies, and protection of their communities. The objectives of this assessment are threefold: 1) to provide the latest information regarding climate change-related risks to the Texas Mid-Coast, 2) to examine the impacts of climate change on key socio-economic and environmental assets in the region and, 3) to explore the adaptation planning, including funding mechanisms for nature-based projects, that can be utilized to address these risks.

The Texas Mid-Coast is an ecologically unique transition zone with a combination of fresh and salt wetlands surrounded by shallow bays and a low salinity environment. These productive ecosystems attract several critical species of aquatic and terrestrial wildlife such as whooping cranes, migratory waterfowl, Kemp's Ridley sea turtles, among others. In addition to serving as habitats, these ecosystems in the Mid-Coast region also provide vital benefits to the surrounding coastal communities, including recreation, employment, flood protection, and carbon sequestration, playing an integral role in the socio-economic development of these areas. The nearby coastal towns, with numerous recreational opportunities, further enhance the economic and cultural importance of the Mid-Coast region.

The Texas Mid-Coast, however, is highly vulnerable to coastal hazards that are expected to become more frequent and severe in the face of a changing climate. The region is expecting greater than the global average increase in sea level rise due to other non-climatic processes such as artificial groundwater and oil/gas extraction that enhance vertical land subsidence. Combined with an increase in storm surge events, the coastal inundation and flooding pose direct challenges to the built and natural infrastructure of the region. The macroclimatic drivers of changes in temperature and precipitation extremes further increase the vulnerability of ecosystems with spillover effects on the dependent species and coastal communities. The expected future growth and development in the region, compounded with climate variability, will lead to changes in coastal habitats, freshwater inflows, and other socio-economic implications.

This assessment distills the larger context of coastal risks down to a localized understanding of the Mid-Coast region's exposure for present and future threats posed by climate change to people and wildlife. It considers a full range of scientifically plausible outcomes using a combination of climate change modeling tools, geospatial tools, literature reviews, and publicly available climate and non-climate related datasets to gain a comprehensive understanding of vulnerabilities of the region. Some of the key findings from this assessment are as follows:

# Climate Change Projections and Exposure

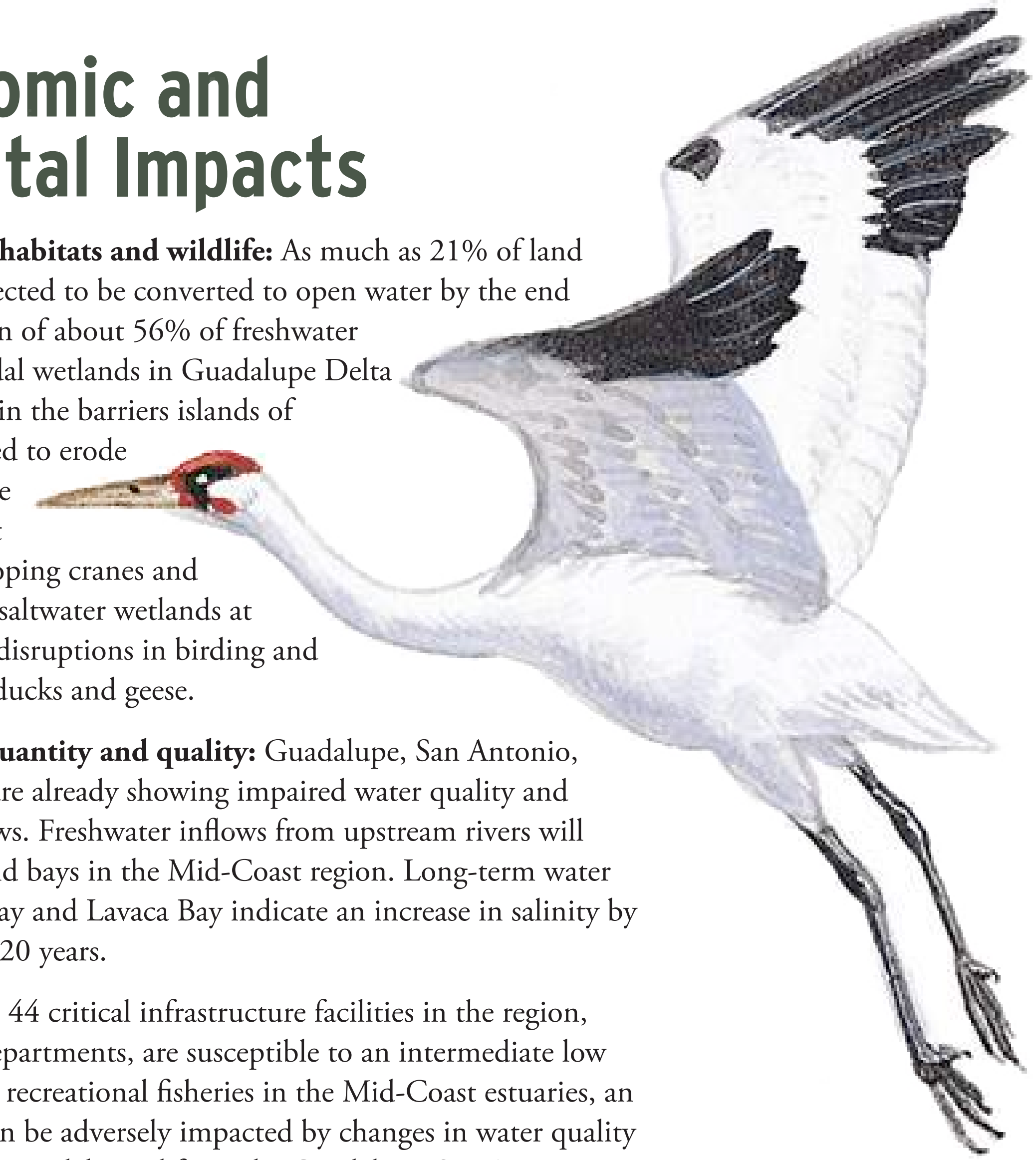
**Sea level rise:** An intermediate low sea level rise scenario (3 feet) will lead to widespread inundation to critical areas such as Matagorda Island unit of Aransas National Wildlife Refuge (NWR), half of the Big Boggy NWR, majority of San Bernard NWR, and Mad Island Wildlife Management Area (WMA). Roads and infrastructure at the coastal towns of Rockport and Aransas Pass will face inundation. The shallow land between Guadalupe Bay and Hynes Bay will be lost, resulting in an intrusion of saltwater in the nearby lakes, bayous, and Guadalupe River streams that flows to the bay. In Jackson, an intermediate low sea level rise will lead to the intrusion of saltwater into the lower Lavaca River basin and other small creeks that empty in Lavaca Bay. Sea level rise at an intermediate level (5 feet) will also pose damages to the parts of Aransas NWR located in Calhoun, and infrastructure located on the coastal strip of Port Lavaca and Port O'Connor. Sea level rise will also increase high tide flooding from seven flood days at present to 60-160 per year by mid-century.

**Storm surge:** Most of Matagorda Island WMA and Matagorda Peninsula and part of Aransas, Big Boggy, and San Bernard NWRs lie in a Category 2 storm surge zone. In the intermediate low sea level rise, the extent of flooding in these areas will significantly increase. New areas will also become vulnerable to a Category 2 storm surge. For example, Guadalupe Delta and Goose Island State Park, which are not currently susceptible to flooding if a Category 2 storm hits Matagorda Island, will face heavy flooding in the future.

**Temperature and precipitation:** The number of days when the temperature dips below zero will follow a negative trend in the future for all the Mid-Coast counties. In a lower-end scenario (RCP 4.5), the Rockport Station data shows about 4.3 frost days by the end of this century from an average of 8.2 frost days in 2010. Days per year with a max temperature above 95°F in Rockport and surrounding Mid-Coast areas are projected to increase from 33.8 in 2020 to 70.8 in 2099 under a lower-end scenario of global emissions. The frequency and intensity of extreme precipitation events and hurricane-induced rainfall are expected to increase under a higher-end scenario in the entire Southern Great Plains region, including the Texas coastline. Sea surface temperature has also been increasing in the Gulf of Mexico and associated estuaries and bays. Based on the measurements from Texas Parks and Wildlife Department, the monthly median temperature in Guadalupe Estuary has increased by about 1.8°F (1°C) between 1990 to 2015 for the months of July to August.



# Socio-economic and Environmental Impacts



**Projected changes to coastal habitats and wildlife:** As much as 21% of land in the Texas Mid-Coast is expected to be converted to open water by the end of the century, with the erosion of about 56% of freshwater wetlands and conversion of tidal wetlands in Guadalupe Delta to open water. Tidal wetlands in the barriers islands of Aransas NWR are also expected to erode and convert to open water. The resulting loss in crucial habitat will be consequential for whooping cranes and migratory waterfowls. Loss of saltwater wetlands at Boggy NWR will also lead to disruptions in birding and nesting sites for thousands of ducks and geese.

**Projected changes to water quantity and quality:** Guadalupe, San Antonio, Colorado, and Lavaca Rivers are already showing impaired water quality and declining 7-day minimum flows. Freshwater inflows from upstream rivers will further impact the estuaries and bays in the Mid-Coast region. Long-term water quality trends in Matagorda Bay and Lavaca Bay indicate an increase in salinity by an average 0.3/year in the last 20 years.

**Key economic sectors:** About 44 critical infrastructure facilities in the region, such as city halls and police departments, are susceptible to an intermediate low sea level rise. Commercial and recreational fisheries in the Mid-Coast estuaries, an important economic driver, can be adversely impacted by changes in water quality and reductions in freshwater flows delivered from the Guadalupe-San Antonio River basin and Colorado-Lavaca River basin. The ecotourism opportunities provided by Aransas NWR, Goose Island State Park, including the coastal tourism sites in the nearby towns such as the fishing piers and beach parks, will also be impacted by changing climate leading to losses in visitor-related expenditures and employment in the region.

**Socially vulnerable population:** Census level data of the six Mid-Coast counties show relatively moderate to high social vulnerability as compared to the other communities in the state. The total population in the Mid-Coast counties of Aransas, Calhoun, Jackson, Matagorda, Refugio, and Victoria will increase by more than 24%, with a positive trend in the population of Hispanic and Non-Hispanic Black people in four out of six counties. Additional factors that contribute to the social vulnerability of the region include a high percent of the population over 65, percent of housing with mobile homes, and percent of the population with disabilities in the region.

In this time of increasing climate variability, local leaders and decision-makers in the Mid-Coast need to account for these risks in their future planning. The vulnerability information gained from this assessment is followed by adaptation assessment to identify existing and potential options and strategies to lower specific climate vulnerabilities and build resilience. With the high importance and vulnerability of vital ecosystems in the region, the assessment calls for a strong investment in nature-based solutions and ecosystem restoration priorities. Plans and projects recently funded by the RESTORE Act, the National Fish and Wildlife Foundation's Gulf Environmental Benefit Fund, the Gulf of Mexico Energy and Security Act, and the Texas Coastal Resiliency Master Plan (Resiliency Plan), among others, are already prioritizing ecosystem conservation and restoration in the Mid-Coast.

The assessment outlines the following policy recommendations for future restoration and adaptation strategies to address climate-related hazards to critical natural and socio-economic assets.

**Conserve and restore wetlands to safeguard whooping cranes and other coastal species to maintain Texas' coastal heritage of recreation and a vibrant seafood industry by:**

- Investing in strategic coastal land acquisitions, expansion, and ecosystem restoration priorities for critical NWRs and WMAs identified in the region, leveraging Deepwater Horizon oil spill and state and federal funding programs identified in this assessment. This includes coordination with partner agencies and private landowners to protect vulnerable wetlands on both public and private lands.
- Working with conservation planners, wildlife biologists, and resource managers to protect winter habitat for whooping cranes. This includes creating incentives for private landowners to provide habitat for the protection of vulnerable and endangered species on their land.
- Implementing living shoreline techniques to reduce the intrusion of saltwater along the bay and protect wetlands, refuge systems, protected areas, as well as improve water quality.

**Ensure enough freshwater reaches Texas' bays and estuaries to maintain (or improve) ecological health of these important ecosystems by:**

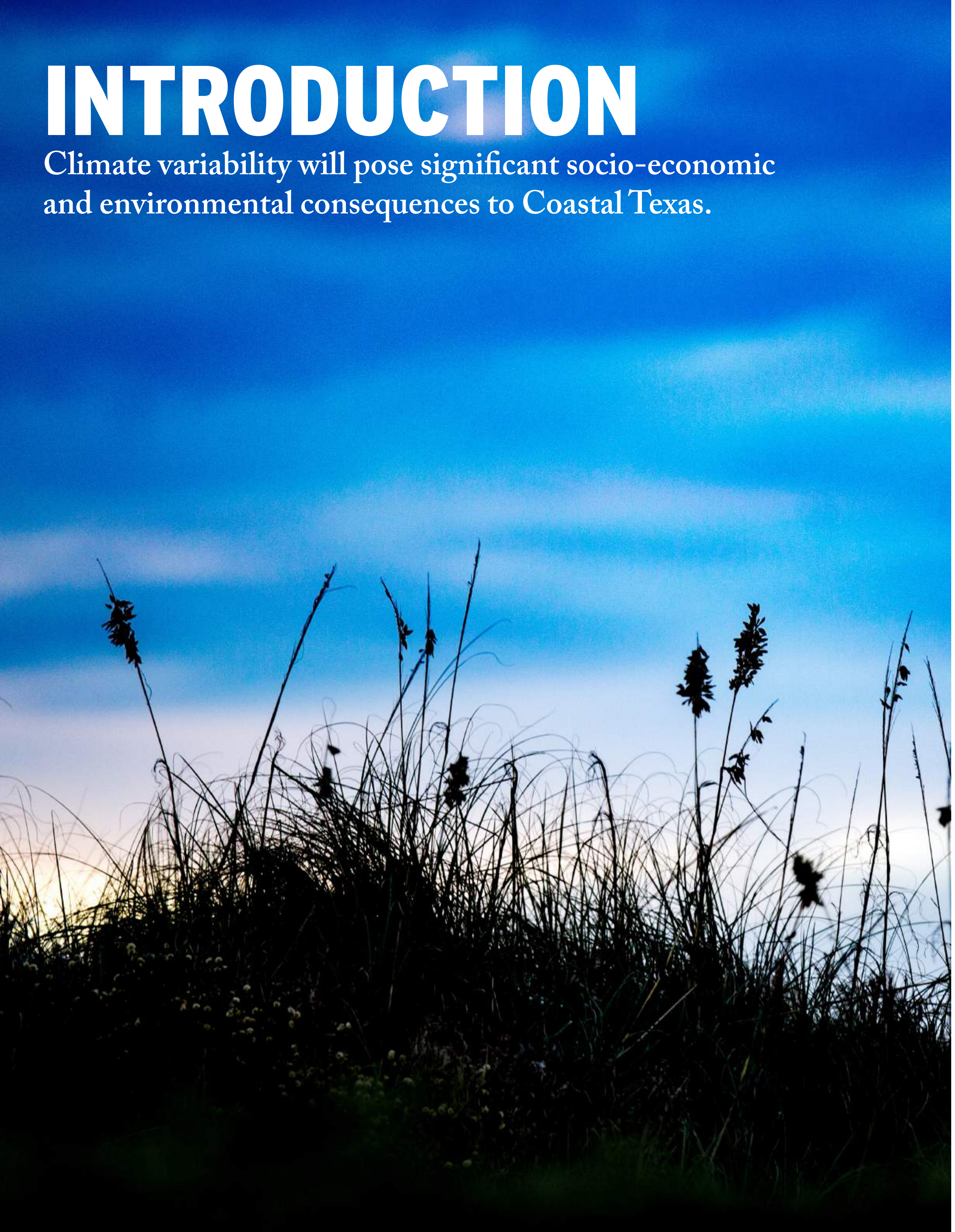
- Conducting studies and analyses to support the revision of environmental flow standards pursuant to the adaptive management process of Senate Bill 3, enacted in 2007, in order to identify flow levels adequate to protect healthy streams, rivers, and bays.
- Establishing set-asides, pursuant to Senate Bill 3, of reasonable amounts of unappropriated water to help maintain critical freshwater inflow.
- Identifying and implementing affirmative strategies for converting some water previously permitted for other uses, including return flows, to freshwater inflow protection as contemplated by Senate Bill 3 to protect freshwater inflows to key habitats.
- Restoring natural hydrological flow by enhancing tidal connectivity where feasible.

**Build resilient coastlines and communities that can withstand projected changes and extreme events by:**

- Prioritizing natural infrastructure and nature-based strategies to shore up coastal resources and defend from extreme storm events, particularly in low to moderate income communities, physically vulnerable areas, and areas with critical facilities identified in this assessment.
- Participating in the Texas General Land Office's Technical Advisory Committee dedicated to scoping and conceptualizing coastal projects for the Texas Coastal Resiliency Master Plan.
- Integrating proactive hazard mitigation and resilience planning by incorporating climate change projections in future coastal development and infrastructure expansion.
- Building up community capacity through shared data repositories for hazards and risks specific to the region and through participatory workshops to help develop their coastal restoration projects. (For example, the Community Health and Resource Management (CHARM) workshops hosted by the Texas Community Watershed Partners of Texas A&M University, and The Coastal Restoration Toolkit developed by Restore America's Estuaries).

# INTRODUCTION

**Climate variability will pose significant socio-economic and environmental consequences to Coastal Texas.**



Climate variability will pose significant socio-economic and environmental consequences to Coastal Texas. To understand these impacts, the decision-makers in the region need to understand the specific climate vulnerabilities and prioritize adaptation strategies for future capital investments. The purpose of this assessment is to equip local leaders and decision-makers in the Texas Mid-Coast with locally relevant information about the area's future related to climate change impacts, enabling them to make greater investments in natural assets to shore up coastal environments for wildlife, local economies, and protection of their communities. It considers a full range of scientifically plausible outcomes that threaten the viability of the region using best-available science. In doing so, the assessment aims to serve as a foundation for decision-makers to make informed choices for the present and future of the Mid-Coast region.

The objectives of this assessment are threefold:

1. To provide the latest information regarding climate change-related risks to the Texas Mid-Coast.
2. To examine the impacts of climate change on key socio-economic and environmental assets in the region.
3. To explore the adaptation planning, including funding mechanisms for nature-based projects that can be utilized to address these risks.

This assessment draws from the best-available science to characterize multiple variables associated with climate change that are likely to interact and lead to compound risks for people and wildlife. The assessment synthesizes diverse sources of information pertaining to physical and demographic trends and projections over the next several decades and evaluates the potential impacts of these changes on critical resources that drive the local economy. It seeks to understand, to the extent possible, how critical assets, like wetlands and whooping crane populations, will change over the coming decades, given projected changes in the system due to natural and human-induced disturbances. This assessment intends to serve as a resource for decision-makers, coastal planners, and restoration practitioners by identifying strategies that ensure the long-term resilience of communities and natural assets in the region.

## 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., 2017) levels. While exploring all these sources is beyond the scope of this work, some state-of-the-art climate science works are discussed in this section to serve as a baseline understanding of climate change vulnerabilities for this assessment.

IPCC's Fifth Assessment Report (AR5) provides robust science on global-scale assessment of observed and projected climate variability. The land and ocean surface temperature data in the report show warming of 1.5°F (0.85°C) for the entire globe over the period of 1880 to 2012 (IPCC, 2013). The annual average temperature in the Southern Great Plains, including Texas, may increase by 3.6°–5.1°F by the mid-21st century and 4.4°–8.4°F by the late 21st century depending on the levels of greenhouse gas emissions (Kloesel et al., 2018).

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 increased 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). With respect to storm surge, the latest IPCC reports do not provide conclusive evidence due to the absence of long-term trends. However, the reports conclude that projections from general circulation models (GCM) under 5.4°F (3°C) to 7.2°F (4°C) of warming indicate an increase in the global number of very intense tropical storms with sea level rise leading to high surge levels (Collins et al., 2019; Hoegh-Guldberg et al., 2018).

Following the third U.S. National Climate Assessment, NOAA released state-level climate summaries to provide localized assessments of climate change across the country. The findings for Texas (Runkle et al., 2017) are summarized below.

- An increase in mean annual temperature by 1°F in the first half of the 20th century which is projected to increase by the end of this century.
- An increase in extreme precipitation and drought intensity.
- An increase in hurricane-related precipitation, surge height, and the intensity of the strongest hurricanes.
- An increase in sea levels between 1 to 4 feet by 2100.

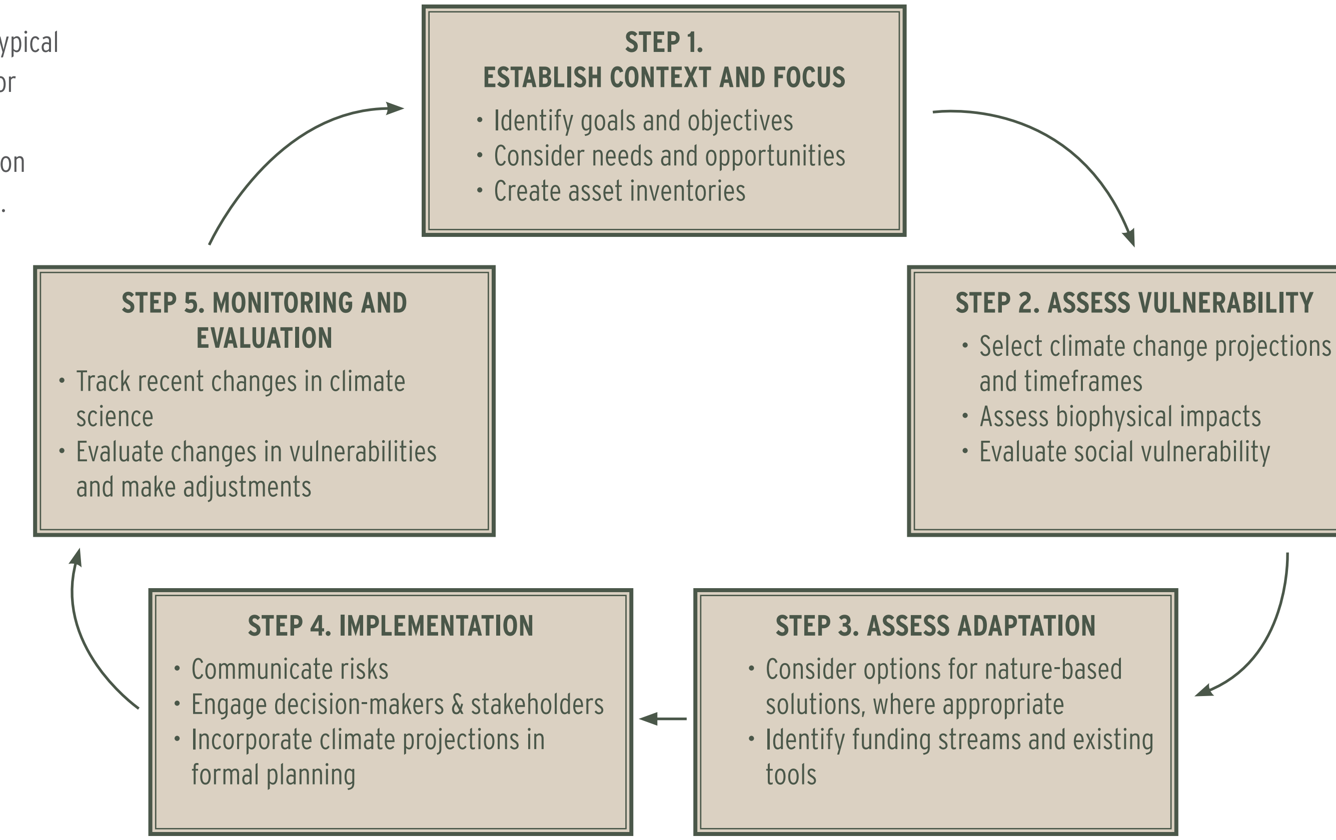
# Analytical Framework

To achieve the first two objectives of this assessment, a vulnerability assessment is performed. As defined by IPCC (2014), vulnerability is the propensity or predisposition to be adversely affected (IPCC, 2014). In climate change literature, vulnerability is a function of exposure to climate-related stressors, sensitivity of social and natural systems, and adaptive capacity of these systems. The recent vulnerability frameworks also integrate social vulnerability, referring to social characteristics of a system, due to its ability to influence sensitivity and adaptive capacity of a system (Binita et al., 2015). An integrated biophysical and social vulnerability framework provides a basis to perform a comprehensive vulnerability assessment. To understand the vulnerability of the Mid-Coast, this assessment begins by characterizing the socio-economic and environmental assets in the study area (Section 2). Exposure is analyzed by identifying climate change projections for the region (Section 3). This is followed by an analysis of how these impacts will affect the Mid-Coast (Section 4) and an assessment of social vulnerability in the region (Section 5).

A vulnerability assessment is a precursor to assessing adaptation planning (Objective 3). Adaptation is defined as the process of adjustment to actual or



**Figure 1.** A typical framework for vulnerability and adaptation assessments.




expected climate and its effects (IPCC, 2014). The goal of adaptation is to moderate or avoid harm or exploit beneficial opportunities to tackle climate change. Adaptation decisions require identifying strategies, funding opportunities, and tools available for resource managers to help communities reduce their vulnerabilities. Section 6 of this assessment delves deeper into adaptation planning with a specific focus on nature-based solutions due to the high importance and vulnerabilities of natural assets in the region. This is followed by policy recommendations to inform future adaptation strategies and efforts in the region.

Conducting a comprehensive vulnerability tailored for local contexts is the first step for bringing the attention of decision-makers towards climate risks and adaptation needs. This is followed by an adaptation assessment to identify existing and potential options and strategies to lower specific climate vulnerabilities and build resilience. To further facilitate the decision-making process, subsequent steps involve implementation and monitoring where the adaptation planning is translated to real-world projects and policies, which are continuously reassessed as the climate science and projections evolve over time. Figure 1 presents a generic framework for assessing vulnerability and adaptation, which is modified to fit the context of this assessment.

This assessment performs the first three steps of the framework to achieve its goals and objectives. The following methods are employed: climate change modeling tools, geospatial tools, literature reviews, and publicly available climate and non-climate related data (Appendix A).Future work stemming from this assessment will focus on supporting Steps 4 and 5 through various risk communication, education, and other outreach efforts.

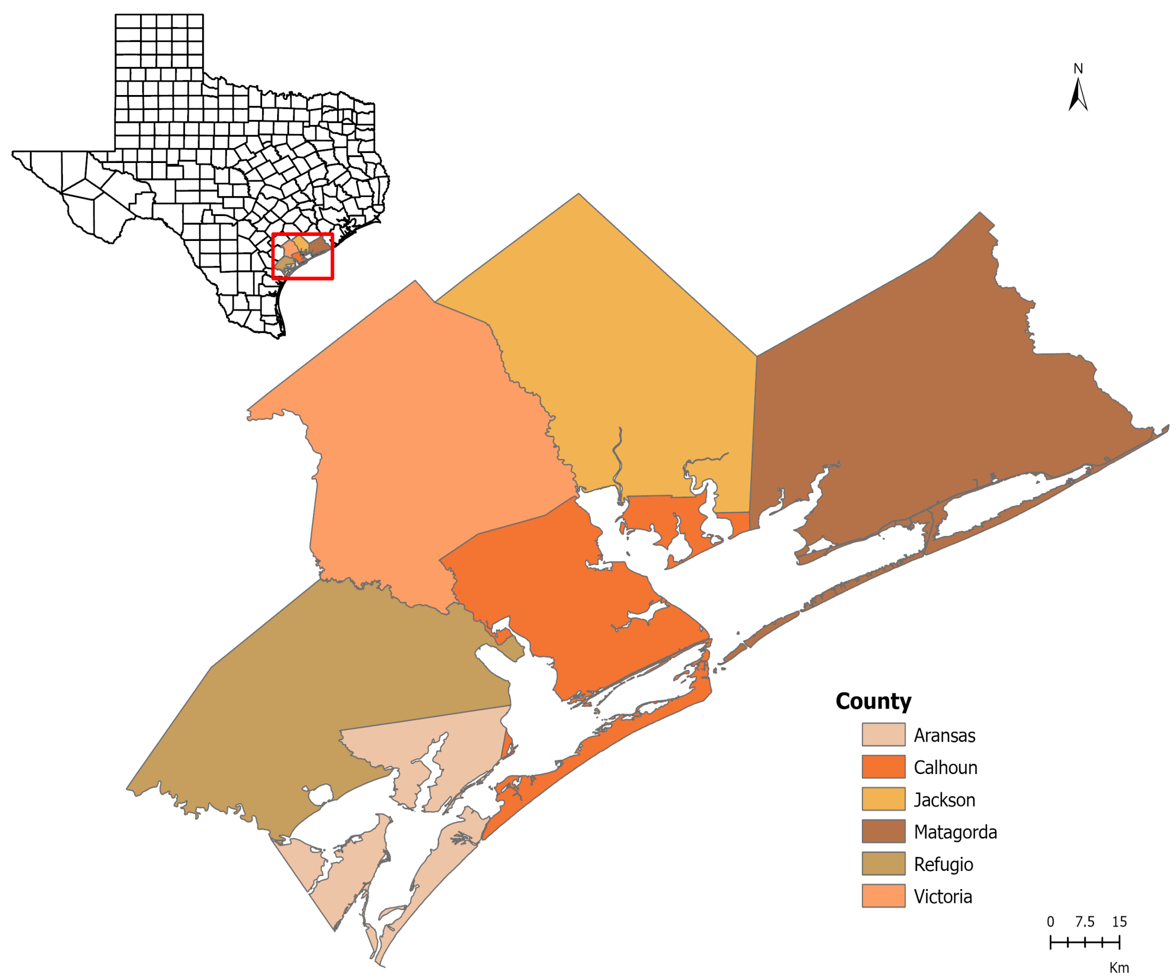



**Figure 2.** Geographic scope of this assessment.

The geographic focus of this work lies on the coastal basins of Guadalupe, San Antonio, Colorado, and Lavaca Rivers. This region includes major estuaries (Guadalupe and Colorado Lavaca), bays (San Antonio, Guadalupe, Lavaca, and Matagorda), and the surrounding counties (Aransas, Calhoun, Jackson, Matagorda, Refugio, and Victoria) (See Figure 2). The next section explains the rationale behind narrowing down on this particular region for conducting this assessment.

# Management Needs and Opportunity

Areas like Houston, Rockport, and Port Aransas suffered major impacts from Hurricane Harvey. Even though the San Antonio Bay and Matagorda Bay areas are eligible for all of the same funding opportunities, compared to other hard-hit areas of the state, this part of the coast seems to be receiving less attention in the various ongoing studies and activities. For instance, the vast majority of investments outlined in the Army Corps' Coastal Texas Protection and Restoration Feasibility Study are in the upper Texas coast, and the projects funded by sources from the Deepwater Horizon oil spill over the last five years are also mostly in the upper coast.

More recently, studies are emerging from other funding sources such as Community Development Block Grant Disaster Recovery (CDBG-DR) funds with a focus on the mid-coast counties. One example is the Economic Development and Strategy Diversification Study (2020) conducted by the Texas General Land Office (GLO) that covered the Aransas, Calhoun, Refugio, and Victoria counties. This study created an inventory of economic assets and deficiencies in the region and provided recommendations with the aim of enhancing resilience to climate hazards. One of the major recommendations was to aid these counties in pursuing state or federal funding opportunities.

The 2019 Texas Coastal Resiliency Master Plan (Resiliency Plan) created by the Texas General Land Office (GLO) has been instrumental in identifying coastal risks, actions, and specific projects for building resilience along the entire Texas Coast in the face of increasing climatic and non-climatic pressures. The Resiliency Plan calls for state's investment in the form of legislative appropriation and other federal, state, and local funding streams to implement priority projects. Additionally, billions of dollars are available to the state of Texas for coastal restoration, flood mitigation, and disaster prevention efforts. These sources of funding result from the Deepwater Horizon oil spill, Hurricane Harvey, and other flooding events, and through other sources like the Matagorda Bay Mitigation Trust, and the revenue sharing provisions in the Gulf of Mexico Energy Security Act. These investment streams represent a significant opportunity to address the region's future and help mitigate threats related to climate change.

# THE TEXAS MID-COAST

**Temperature sensitivity, combined with accelerating rates of relative sea level rise and changing rainfall regimes, leaves coastal wetlands across this region of Texas highly vulnerable and in a state of flux.**

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## Overview of the Mid-Coast Region

The Texas Mid-Coast is situated within an ecological transition zone teeming with environmental assets such as wetlands and associated wildlife. The Mid-Coast receives freshwater inflow from the San Antonio and Guadalupe River basins that flow into the Guadalupe estuary and San Antonio Bay and the Colorado and Lavaca Rivers that flow into the Matagorda Bay. However, this region is highly vulnerable to storms, sea level rise, changes in extreme temperatures and rainfall regimes (Osland et al., 2013, 2016). Tidal saline wetlands are comprised of a combination of salt marshes and mangrove forests, and their relative abundance is largely driven by the frequency and intensity of extreme cold temperatures. For instance, relatively small declines in the occurrence of extreme winter lows can cause dramatic changes to the ecosystem structure and function of wetlands in the form of inland mangrove expansion and salt marsh displacement. Freshwater wetlands in the region are susceptible to changes in upstream freshwater inflows and displacement by saltwater intrusion. Additionally, the temperature and precipitation changes threaten the viability of critically important wildlife and migratory birds that are dependent on the health of these wetlands. This temperature sensitivity, combined with accelerating rates of relative sea level rise and changing rainfall regimes, leaves coastal wetlands across this region of Texas highly vulnerable and in a state of flux.

These climate-induced changes also impact other ecosystem services that drive many local and regional economic activities such as fishing, birdwatching, and associated ecotourism in the Mid-Coast. Sea level rise and storm surge directly threaten the coastal infrastructure in the Mid-Coast counties, which are experiencing a higher than average rate of sea level rise. Understanding how sea level rise and changing inundation regimes, as well as extreme temperatures and precipitation, will interact with expected growth and development in the region needs closer scrutiny to enable resource managers to prepare for the effects of climatic drivers on coastal wetland community assemblages.

The following subsections outline the culturally and economically important natural assets of the region that are at risk but vital to the cultural heritage and the local and regional vibrancy of the Texas Mid-Coast.

## Regional Environmental Assets

The Texas Mid-Coast is home to ecologically important hardwood wetland forests, associated wetlands, and coastal prairies. Figure 3 provides an overview of environmental assets in the region, including watershed boundaries, National Wildlife Refuges (NWRs), Wildlife Management Areas (WMAs), and State Parks.

Two out of the seven major estuaries in Texas are located along the Mid-Coast region. The natural rainfall patterns in Texas create a north-south gradient in the estuaries with decreasing freshwater flow and increasing salinities moving southward (Bugica et al., 2020). The Mid-Coast estuaries rely on the quantity and quality of freshwater inflows from rivers and creeks to maintain their salinity, nutrient, and sediment regimes. The Guadalupe Estuary, which includes the San Antonio Bay, surrounds the Mid-Coast counties of Aransas, Refugio, and Calhoun. The freshwater inflow from Guadalupe and San Antonio Rivers in the Guadalupe estuary creates a salinity gradient and provides nutrients and sediments critical to the estuary-dependent species such as fish, shrimp, and oysters. Another significant estuary in the upper Mid-Coast of Matagorda, Jackson, Victoria, and Calhoun counties is the Colorado-Lavaca Estuary. The estuary, including the Matagorda Bay and Lavaca Bay, is the second largest in the state and receives more than 3 million acre-feet of freshwater inflow from the Colorado and Lavaca Rivers (TWDB, 2021).

As much as 55% of the land area in Aransas County is covered with wetlands (NOAA, 2016). Sites such as Aransas NWR in the Mid-Coast serve as habitat to various species due to their unique ecosystems. The Aransas NWR is surrounded by shallow bays resulting in a shift of the wetland ecosystem from estuarine to freshwater. The Matagorda island unit of the NWR is primarily composed of barrier islands extending down the Texas coastline. Big Boggy NWR and parts of San Bernard NWR in Matagorda County are internationally significant shorebird sites and together form a part of the Texas Mid-Coast Refuge Complex. These two NWRs consist of several coastal wetlands, including salt and freshwater marshes, ponds, and coastal prairies.

About 15,000 acres of Mid-Coast wetlands are preserved and protected in Guadalupe Delta WMA and Mad Island WMA. Guadalupe WMA units in Calhoun, Victoria, and Refugio are predominantly freshwater marshes receiving water from the Guadalupe River. Mad Island WMA is a 7200-acre area consisting of fresh, intermediate, brackish, and saline marshes.

A diversity of wildlife flourishes in these protected habitats of the Mid-Coast. Coastal prairies in the Aransas NWR provide habitat for federally listed species such as whooping cranes. In the winter of 2019-2020, 509 whooping cranes migrated to the Aransas NWR near Austwell. Young blue crabs, the primary food source of whooping cranes, also seek the low salinity of Aransas NWR. The Matagorda Island Unit of the Aransas NWR is home to reddish egrets, alligators, and coyotes (FWS, 2020). The beach and dune system of barrier islands also provide nesting grounds for Kemp's Ridley sea turtles. The low salinity and shallow environment of the Guadalupe delta further attract several other threatened and endangered species such as brown pelican, reddish egret, and white-faced Ibis (TPWD, n.d.). The 4500 acres of salt marshes in Big Boggy harbor more than 55,000 geese and 15,000 ducks annually. Big Boggy and San Bernard NWRs are home to more than 300 species of birds with waterfowl and neotropical migratory songbirds using these areas as crucial points in their journey across the Gulf.

# Regional Socio-economic Assets

The economic stability and prosperity of the Texas Mid-Coast region is inextricably linked to the health of the Gulf of Mexico and associated bays. A healthy marine life of the Guadalupe and Colorado-Lavaca estuaries is an integral part of the commercial and recreational fishing industry through providing employment opportunities across the Mid-Coast counties. As of 2015, ocean-related businesses in Refugio and Aransas counties provided 25% of the total jobs in these counties, representing a 52% and 26% increase since 2005, respectively (NOAA, 2016). In Calhoun County, ocean-related jobs grew 70% from 2005 to 2015 (NOAA, 2016). In Jackson, jobs in



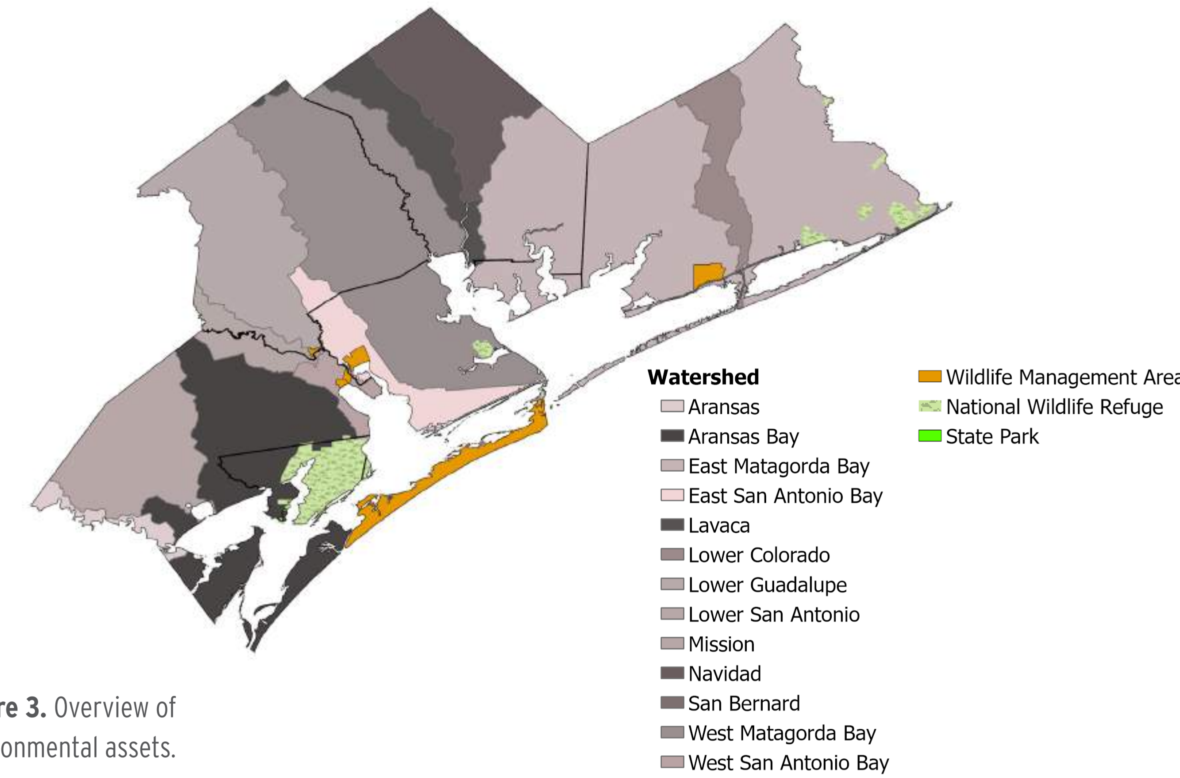
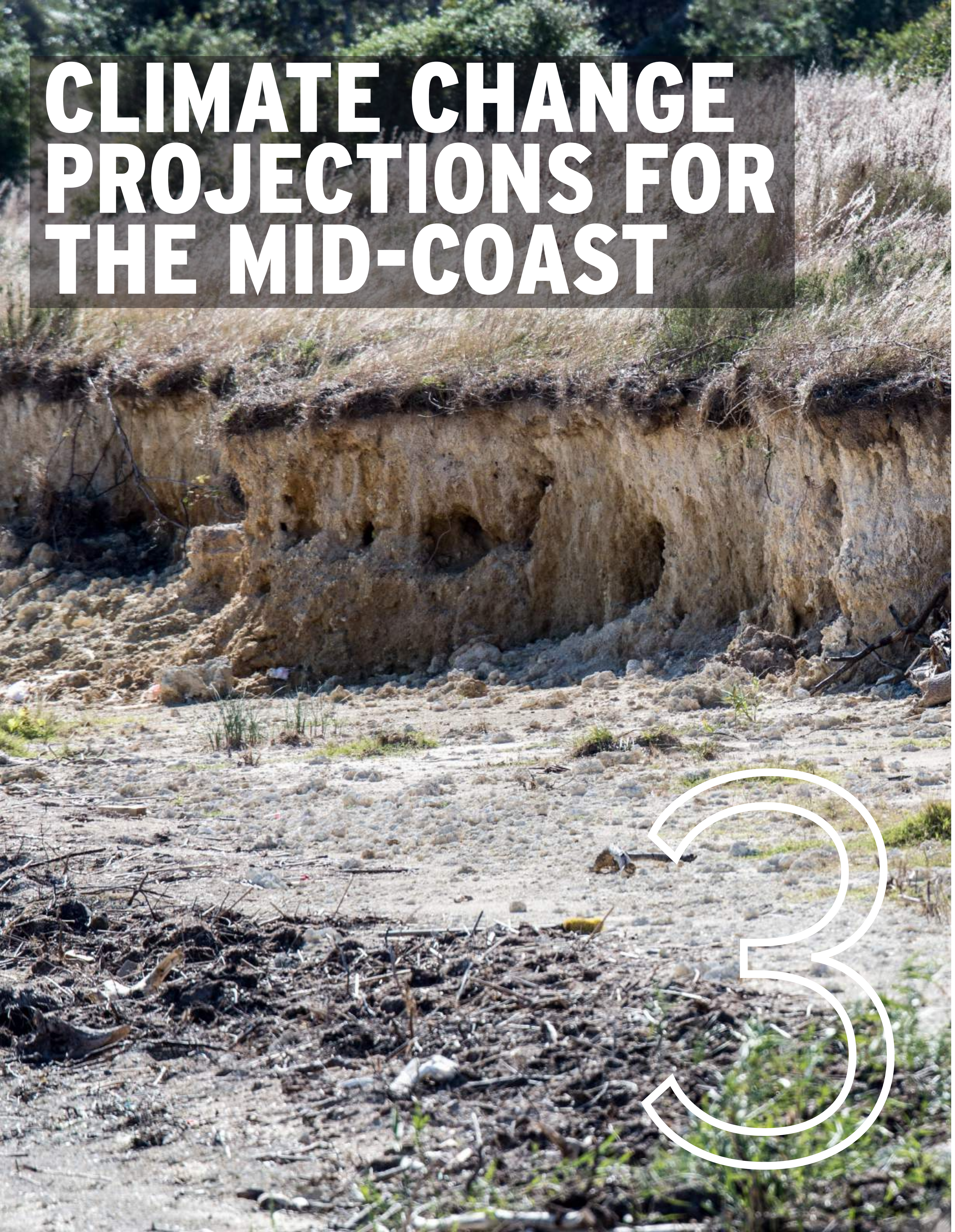



**Figure 3.** Overview of environmental assets.

ocean-related businesses provided 13.1% of total jobs marking a 68% increase from 2005 (NOAA, 2016). As compared to the rest of the state, the economic output generated by the oil and gas industry is not a significant driver in these counties. For instance, offshore mineral extraction contributed to more than 52% of the ocean jobs in the state. However, with the exception of Refugio (63.6%), the contribution of such activities to the ocean-related economy had been 20.2% to Aransas and 7.1% in Jackson with no offshore mineral extraction jobs in the remaining counties since 2005. On the other hand, the tourism and recreation sector constitute a major part of these ocean-related jobs in this region, accounting for more than half of such jobs in Aransas (75.5%), Calhoun (53.3%), and Matagorda (63.7%) counties.

In 2019, the tourism sector generated about $490 million in direct travel spending in Aransas, Calhoun, Jackson, Matagorda, Refugio, and Victoria counties (Travel Texas, 2019). With its idyllic beaches and quaint coastal towns, the Mid-Coast region provides several recreational opportunities and attracts millions of visitors. The coastal town of Seadrift, a popular choice for fishing and paddling activities, has been experiencing positive growth in direct travel spending by the visitors over the last ten years. The Aransas NWR is also an attractive recreational site and adds to the economic opportunities to the local communities of Aransas, Calhoun, and Refugio counties. In 2017, about 84,000 visitors spent a total expenditure worth $2.5 million on activities related to wildlife photography, auto tour, visitor center, etc., in the Aransas NWR (FWS, 2019). Goose Island State Park covers 321 acres and attracts over 190,000 visitors annually for hiking, camping, and fishing. Matagorda Bay Nature Park, a 1,333-acre park and nature preserve, is another popular spot for birdwatching and wetland paddling. With a growing fondness for outdoor recreation due to the looming pandemic, ecotourism in the Mid-Coast is bound to increase in the short term. Population expansion in the longer term will further add to an influx of visitors to these coastal areas thriving with wildlife and ecological resources.



# CLIMATE CHANGE PROJECTIONS FOR THE MID-COAST

3

This section describes existing trends and projections for various climate-induced hazards that pose threats to the Texas Mid-Coast region. It focuses on three key climate change projections: sea level rise, storm surge, and changes in temperature and precipitation. Consistent with global studies such as IPCC AR5 (IPCC, 2014), national studies such as Fourth National Climate Assessment (Avery et al., 2018), and local studies such as Resiliency Plan, a timeframe of 2100 is chosen for the projections in this assessment.

## Sea Level Rise and Inundation Regimes

The Texas coastline has experienced a rise in sea levels by 0.4-1.4 feet over the past 100 years, depending on local topography and rate of subsidence (Runkle et al., 2017). In the Texas Mid-Coast, relative sea level is projected to increase between 2.82 to 9.32 feet by 2100, depending on the future scenarios. The relative sea level rise trends, highest in Texas and Louisiana, enhance the global sea level rise by about 0.5-2 mm/year as it takes into account regional changes in ocean circulation and local vertical land motion, thereby providing an estimate of sea level rise based on specific local variations. The relative sea level rise in Texas, including the Mid-Coast, is expected to be greater than the global average due to other non-climatic processes such as artificial groundwater and oil/gas extraction that enhance land subsidence (Sweet et al., 2017).

This assessment utilizes relative sea level rise data from NOAA to identify and map the areas vulnerable to permanent inundation in the Texas Mid-Coast. Based on NOAA's relative sea level rise projections for the nearest location (Rockport, TX), four local scenarios – Intermediate low (3 feet), Intermediate (5 feet), Intermediate high (7 feet), and High (9 feet) – are used to show the areas at risk by 2100 (Figure 4). In Rockport, TX, the historical observations depict a 5.86 mm/year increase in relative sea level rise trend from 1973 to 2020. It is worth noting that future projections in Rockport are slightly higher than the nearest tide gauge located in Corpus Christi, indicating a higher vertical land movement along this stretch of the coastline. Figure 4 provides an overview of the Mid-Coast's vulnerability under different sea level rise projections. Matagorda Peninsula, a strip of land between Matagorda Bay and the Gulf of Mexico, will face significant inundation with an intermediate low sea level rise. In Jackson, an intermediate low sea level rise will lead to the intrusion of saltwater into the lower Lavaca River basin and other small creeks that empty in Lavaca Bay.

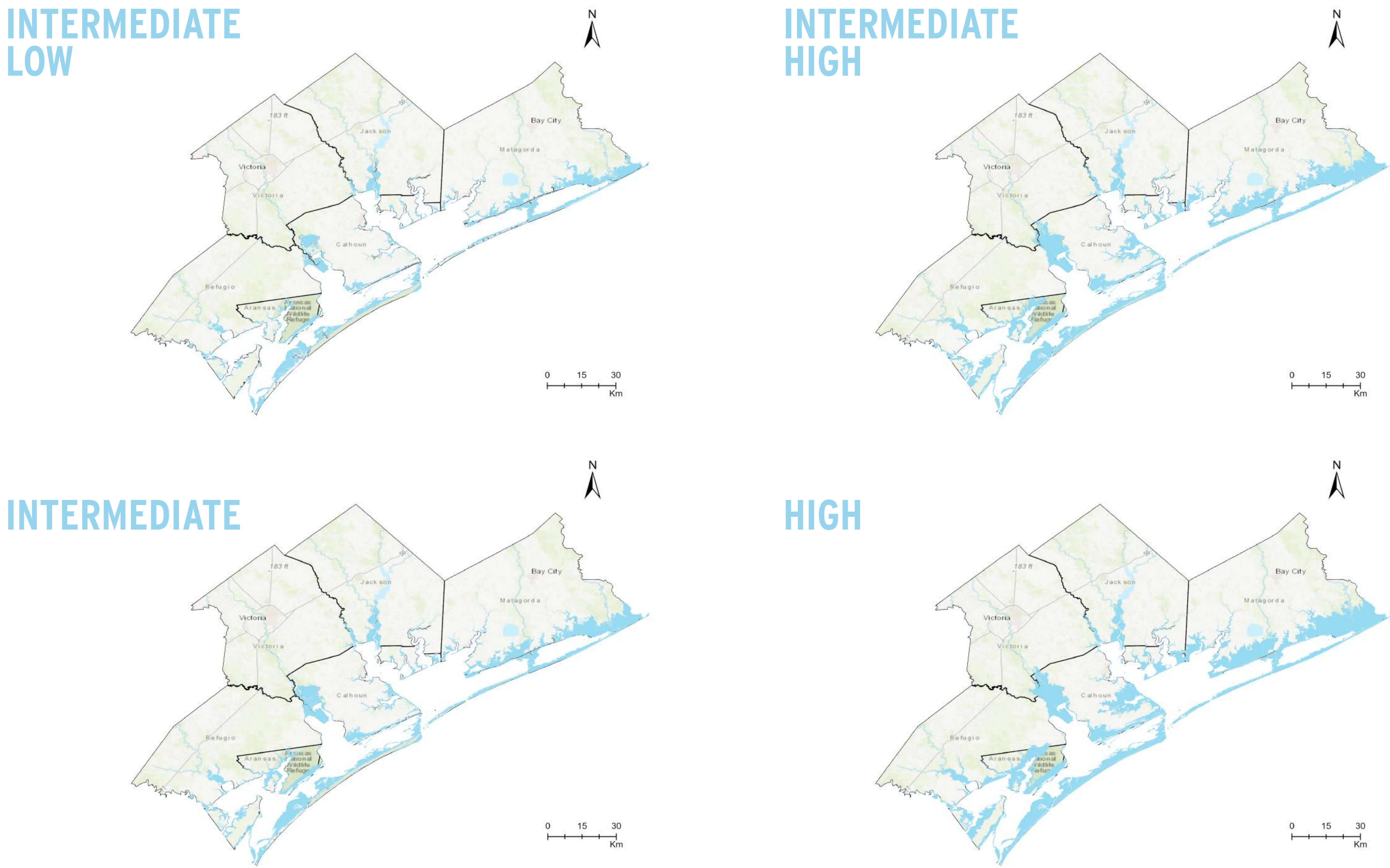
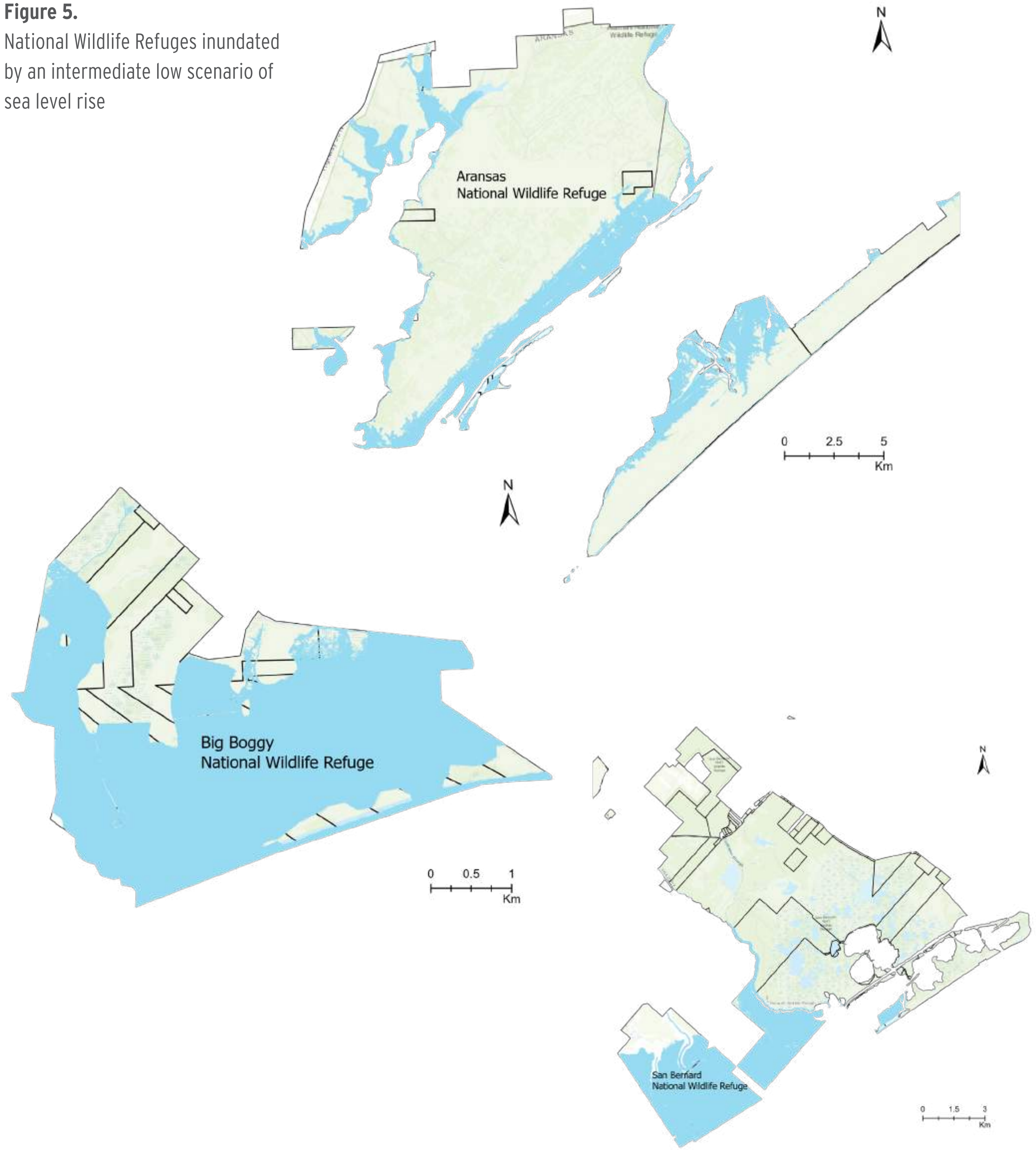



**Figure 4.** Inundation caused by four different scenarios of sea level rise.

Figure 5.
National Wildlife Refuges inundated by an intermediate low scenario of sea level rise



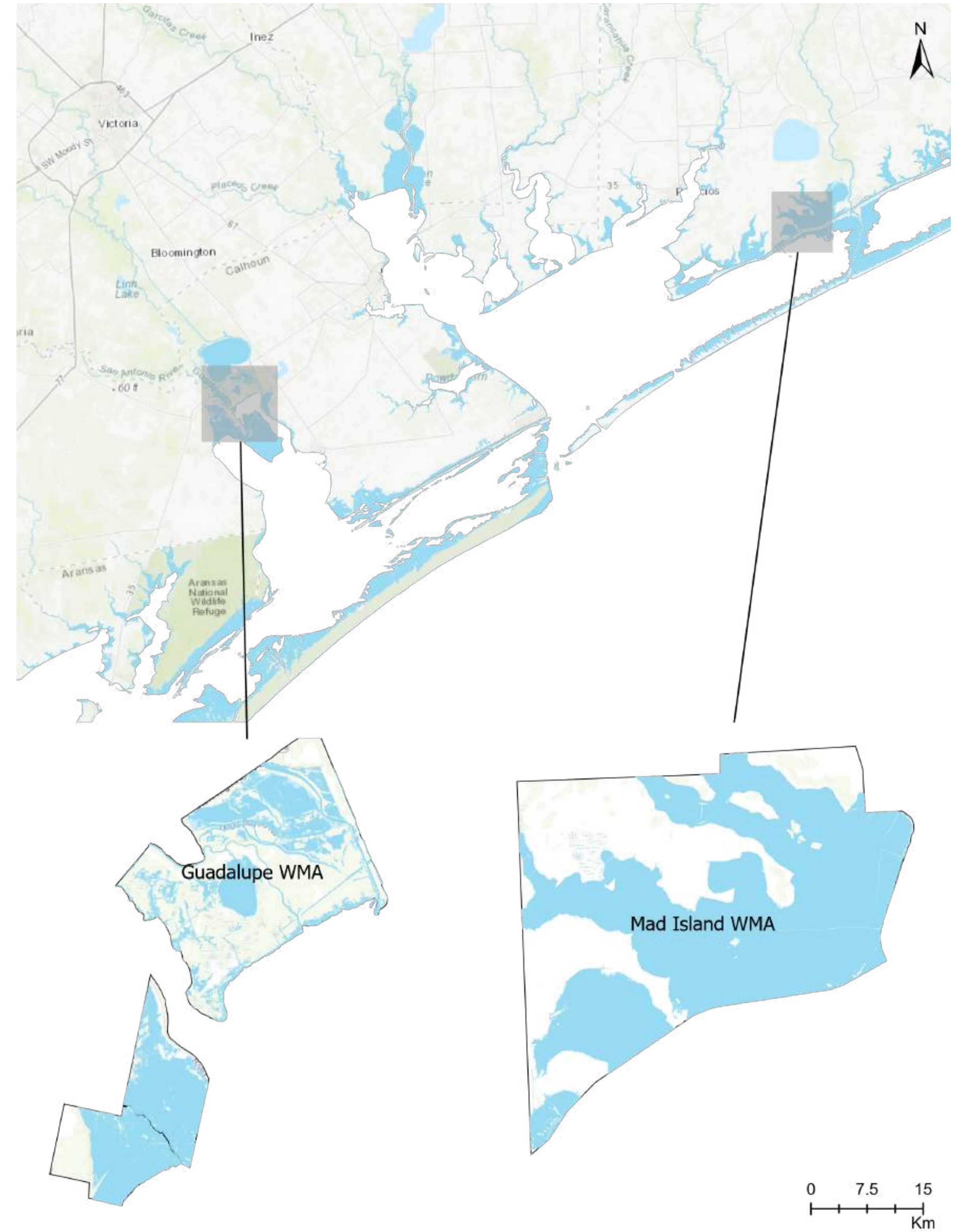
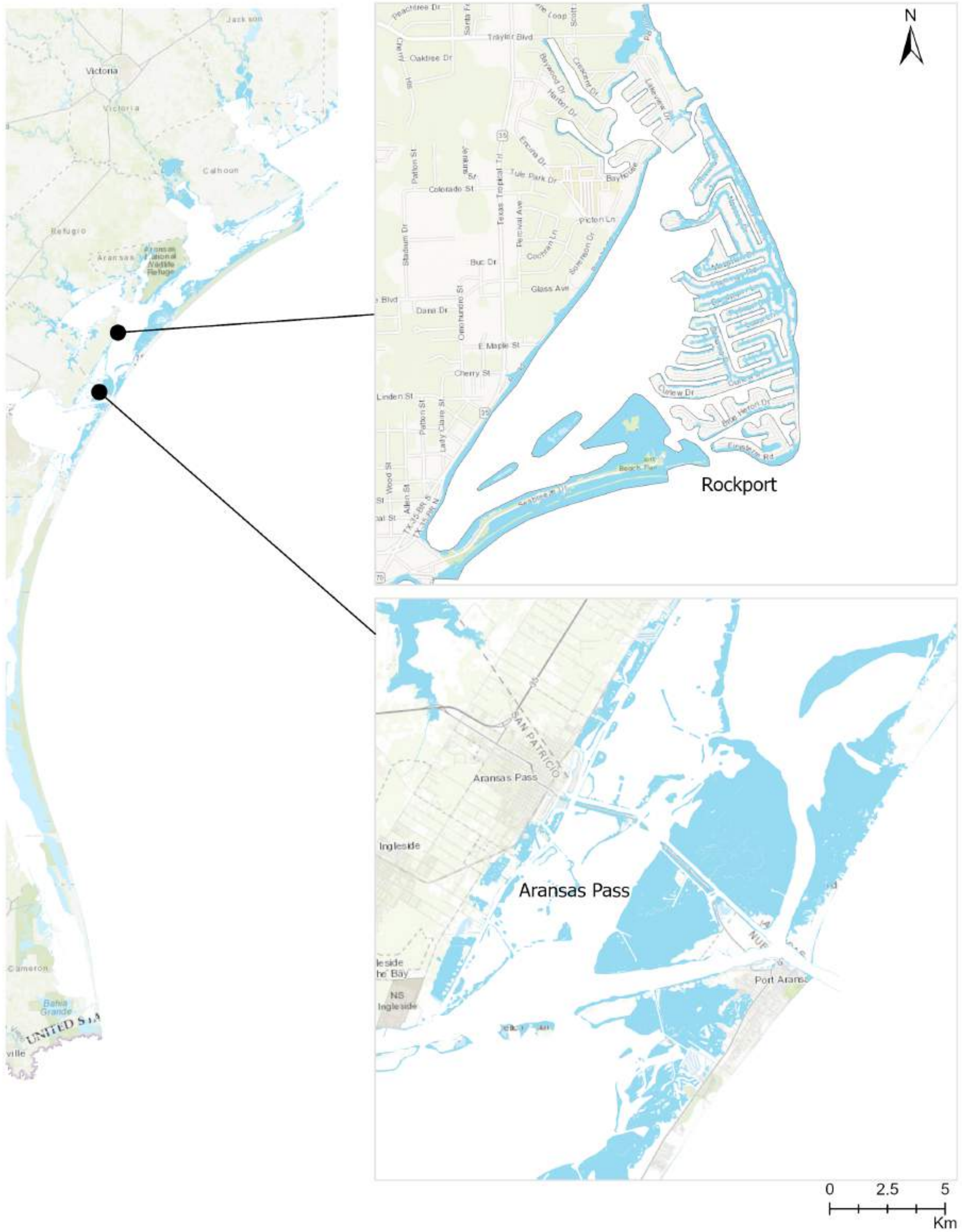




Figure 6.
Wildlife Management Areas inundated by an intermediate low scenario of sea level rise.

Figure 5 presents NWR areas that will experience widespread inundation with an intermediate low sea level rise by 2100. At this point, most of the land area of the Matagorda Island unit of Aransas NWR is likely to lose land and convert to open water. Around the east Matagorda Bay, the majority of the San Bernard NWR located in the county and half of the Big Boggy NWR will face inundation.

Even at an intermediate low estimate of sea level rise, parts of the Guadalupe delta surrounding Mission Lake will be inundated (Figure 6). The shallow land between Guadalupe Bay and Hynes Bay will be lost, resulting in an intrusion of saltwater in the nearby lakes, bayous, and Guadalupe River streams that flows to the bay. A 3 feet sea level rise will also lead to land loss at Mad Island WMA (Figure 6).

**Figure 7.** Key areas inundated by an intermediate low scenario of sea level rise.




Sea level rise will inundate the roads and infrastructure in the coastal towns of Rockport and Aransas Pass (Figure 7). The popular visitor attractions such as the Rockport beach and fishing pier will be impacted by an intermediate low increase of 3 feet in sea level rise. Matagorda Bay Nature Park and the surrounding Colorado River will also face significant risk due to inundation and intrusion by sea level rise.



**Figure 8.** Key areas inundated by an intermediate scenario of sea level rise.


Sea level rise at an intermediate level (5 feet) will also pose damages to the physical and natural infrastructure located on the coastal strip of Port Lavaca and Port O'Connor, such as Port Lavaca Bird Sanctuary, Fishing Pier park, and several small tourism businesses. The sea level rise will also lead to significant inundation at Aransas NWR in Calhoun (Figure 8). Majority of the Matagorda Peninsula and Matagorda Beach will be inundated at this point.

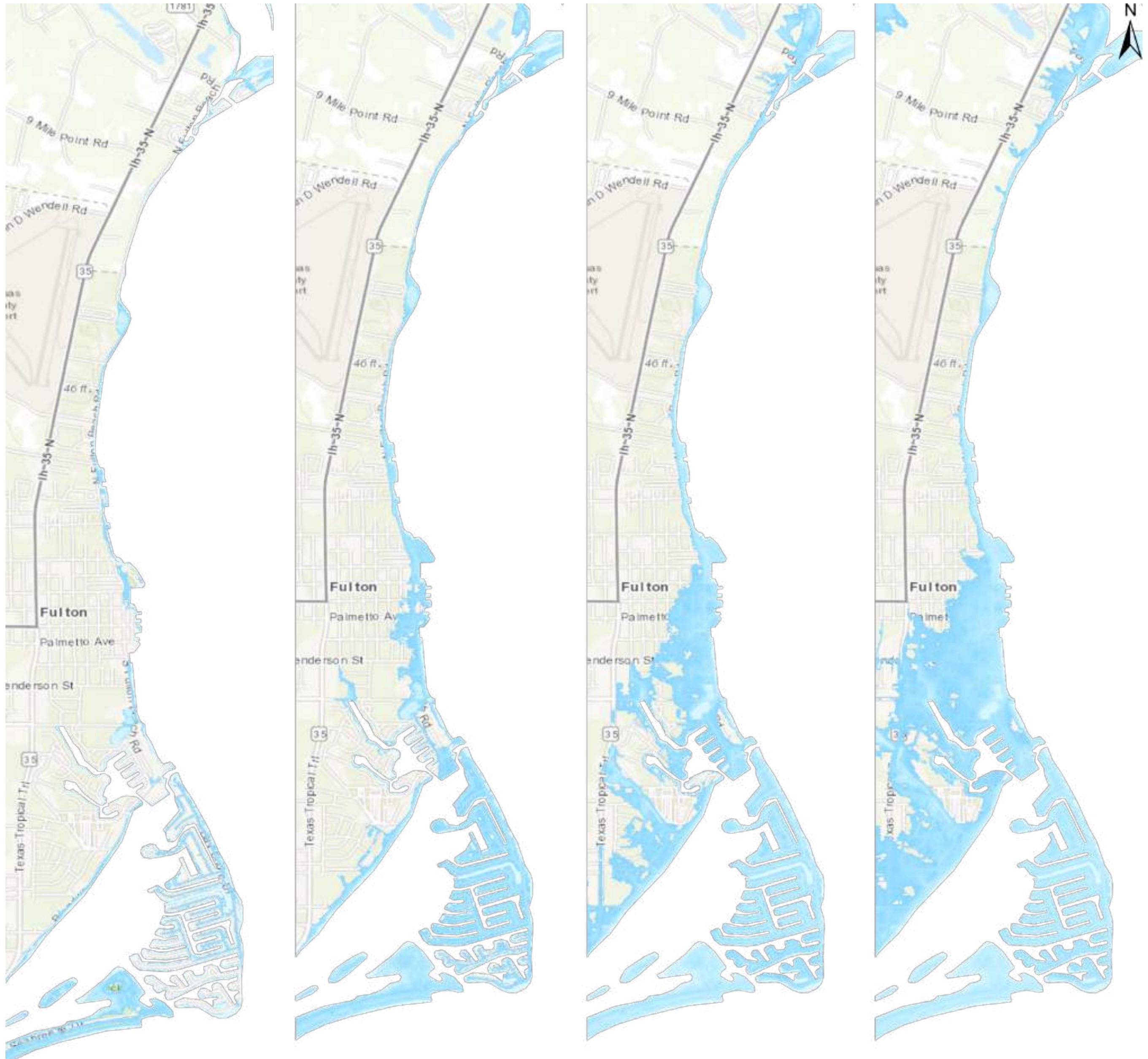



**Figure 9.** Increase in inundation regimes in the Rockport-Fulton coastline with an increase in sea level rise.

Inundation is likely to continue in these areas with an increase in sea level rise. For instance, in Fulton, the extent of inland seawater intrusion and inundation continues to increase with sea level rise (Figure 9). An intermediate high scenario (7 feet) threatens the future existence of other Mid-Coast towns such as Port Lavaca, whereas other places such as Seadrift and Palacios will lose vital tourism infrastructure that is essential for their survival. The sea level rise projections only show slight flooding for Austwell at an intermediate-high scenario.

In many of these low-lying Mid-Coast areas, high-tide flooding will also become more frequent due to an increase in relative sea level rise. The Rockport tide gauge shows seven high-tide flooding days at present from only one day in 2000. The number of flood days is projected to increase to 60-160 per year by mid-century. While these events are temporary in nature, it still damages the infrastructure through flooding roads, streets and storm drains. Along the Texas coast, high-tide flooding is also likely responsible for impaired groundwater quality due to saltwater intrusion in the aquifer (Sweet et al., 2020).



Decision-makers need to prioritize the areas at risk of an intermediate low scenario of sea level rise in their planning. In the worst-case scenario where high estimates of global emissions continue, the sea level will accelerate much faster, reaching above the 3 feet levels by as early as 2060. Coastal planners in the Mid-Coast are also charged with the additional responsibility of dealing with other non-climatic factors that are enhancing the rate of sea level rise in the region. Risk-averse decision-makers also need to consider the intermediate high to high scenarios of sea level rise that would wreak havoc in the Texas Mid-Coast and threaten a majority of the areas with environmental and socio-economic importance.

# Coastal Storms and Storm Surge

Over the past 20 years, Texas has witnessed several major hurricanes such as Hurricane Rita (Category 3), Hurricane Ike (Category 2), and most recently, Hurricane Harvey (Category 4). These hurricane events posed hazards due to widespread coastal flooding, extreme rainfall, and associated winds in the Mid-Coast. For example, San Antonio Bay's western shores experienced the highest inundation (8 to 10 feet) due to the combined effects of storm surge and tide during Hurricane Harvey (Blake & Zelinsky, 2018). The barrier islands in Matagorda experienced storm surge inundation of 4 to 7 feet above ground level. Climate change is expected to increase the frequency of severe Category 4 and 5 hurricanes such as Harvey (Kossin et al., 2020). The damage potential of these hurricanes will further increase with a potential rise in sea level.

In this assessment, the areas under risk of storm surge inundation are identified using the data available through the Resiliency Plan. The Resiliency Plan uses Maximum of the Maximum Envelopes of Water (MOMs) outputs for a Category 2 storm produced from Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. To investigate the areas threatened by a future increase in sea level rise by 2100, the Resiliency Plan delineates storm surge zones for Category 2 plus 3 feet (1 meter) of sea level rise scenarios using the Sea Level Affecting Marshes Model (SLAMM) outcome. Layers containing the maximum inundation extent under the present and future scenario of 1 meter sea level rise for the relevant Mid-Coast region are extracted and modulated in ArcGIS Pro.

Figure 10 provides an overview of the area susceptible to the current storm surge zone by a Category 2 hurricane in the Texas Mid-Coast. It includes most of Matagorda Island WMA and Matagorda Peninsula and part of Aransas, Big Boggy, and San Bernard NWRs. In the intermediate low sea level rise, the extent of flooding in these areas will significantly increase.

Depending on the landfall location, new areas will also become vulnerable to a Category 2 storm surge, for example, Guadalupe Delta and Goose Island State Park, which are not currently susceptible to flooding if a Category 2 storm hits Matagorda Island, will face heavy flooding in the future. In case of a storm hitting the Matagorda peninsula, areas such as Mad Island WMA that are slightly flooded at present will become prone to higher levels of flooding in the future (Figure 11).

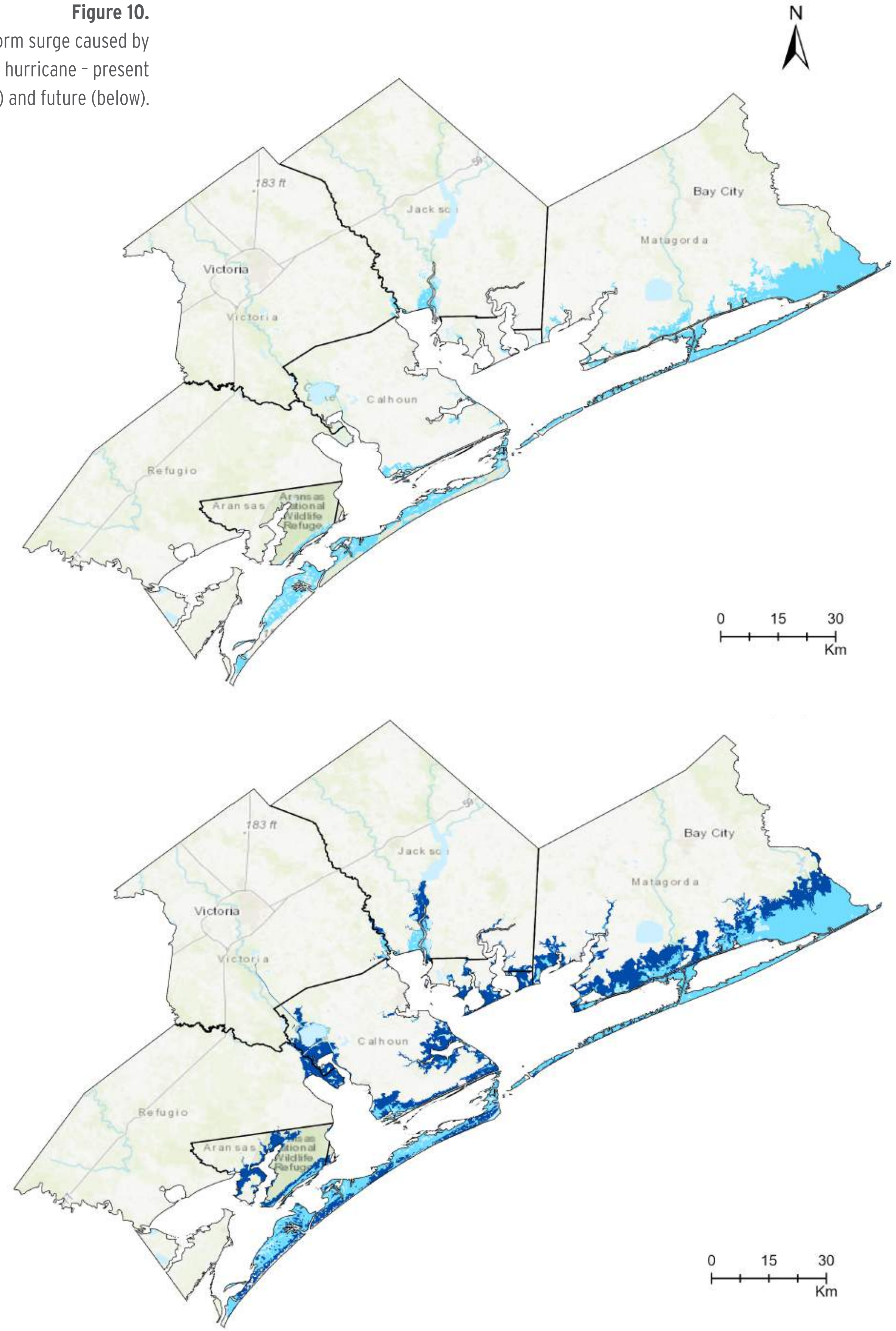



**Figure 10.**
Changes in storm surge caused by a Category 2 hurricane – present (above) and future (below).

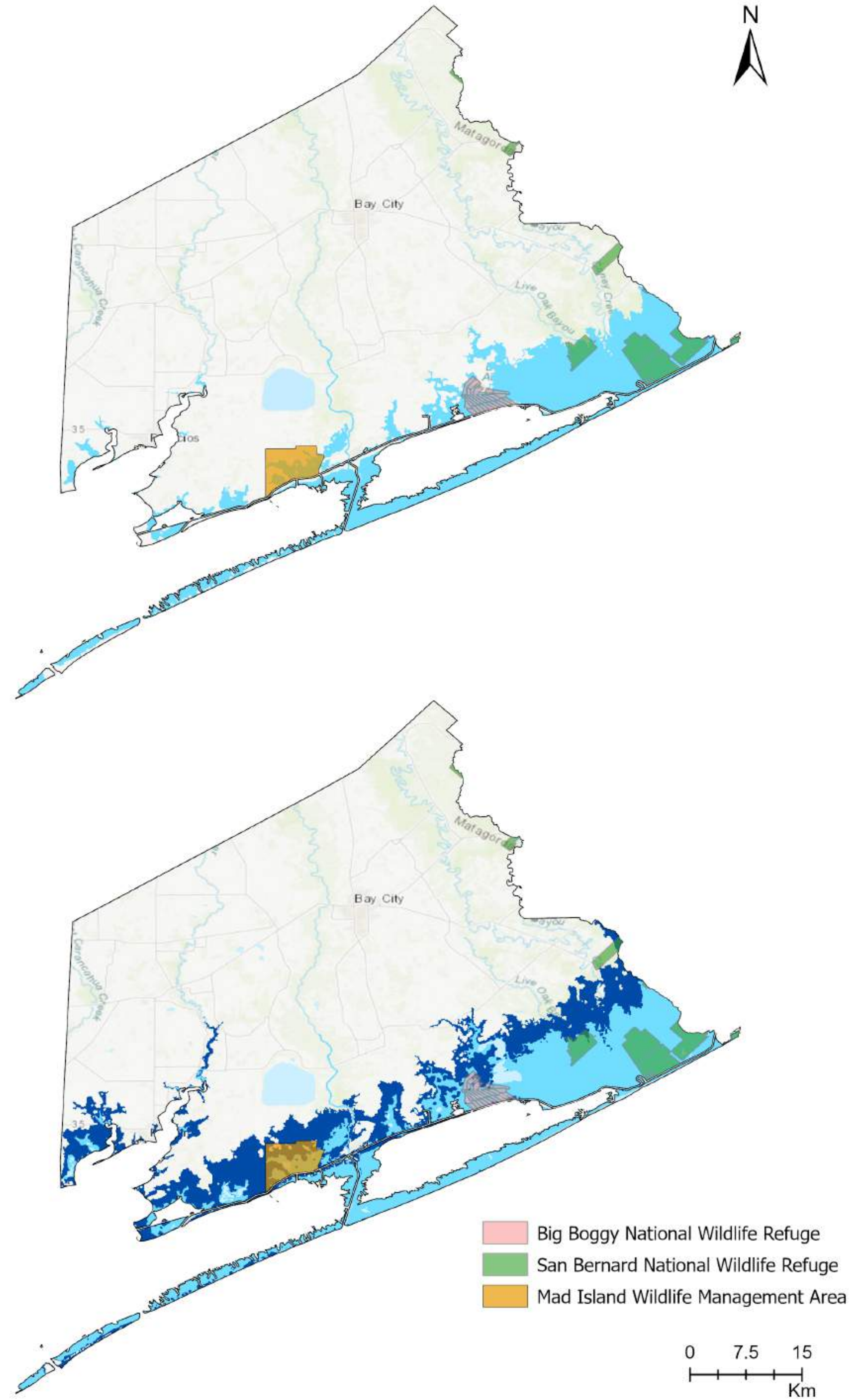



**Figure 11.**
Changes in storm surge caused by a Category 2 hurricane in Matagorda Bay – present (above) and future (below).

Even a storm making landfall further south in Padre Island will cause flooding in the Mid-Coast counties of Aransas, Calhoun, and Refugio. In Aransas County, the vulnerability of surge-related flooding will increase drastically in the Rockport-Fulton area with a future 3 feet sea level rise.

Decision-makers need to consider two important points. Firstly, the risks associated with low-probability, high-consequence events such as a Category 5 storm cannot be neglected in current and future adaptation planning. Failure to account for these higher category hurricanes may result in loss of assets and, at times, life in the Mid-Coast region. Secondly, and more importantly, the current level of hurricane planning, if only focused on gray infrastructure, will not keep up with the future climatic changes. Recent research has corroborated the fact that the frequency of high-intensity storms (Category 3-Category 5) will increase with climate change (Kossin et al., 2020; Walsh et al., 2016). Keeping this in mind, the Category 2 scenario used in the Resiliency Plan does not adequately reflect the future surge conditions. Additionally, the MOM output used in the study also provides a conservative estimate of maximum inundation for a particular hurricane category as it does not consider the wind-driven waves that further increase the storm surge height (Glahn et al., 2009).

# Extreme Temperature and Precipitation

Texas is expected to experience warming under all future scenarios. This warming will increase the number of extremely hot days and a decrease in the number of cold days (Runkle et al., 2017). For instance, the number of days when the temperature dips below zero will follow a negative trend in the future for all the Mid-Coast counties. The assessment uses station data created by the Climate Explorer (NOAA) that provides downscaled results generated by global climate models for the Coupled Model Intercomparison Project Phase 5 (CMIP5). In a lower-end scenario, Aransas, Refugio, Victoria, and Calhoun counties will witness about 4.3 frost days by the end of this century from an average of 8.2 frost days in 2010. Less than 2 frost days are expected by the end of the century if we continue to a worst-case scenario of future emission concentrations. The projections for upper Mid-Coast counties of Jackson and Matagorda show the frost days reducing by half in 2021 compared with 2010 levels under a low-emission scenario. Frost days will decrease by more than 80% under a high-emission scenario from about 11 days in 2010 to 2 days in 2021.

On the other hand, days per year with a max temperature above 95°F in Rockport and surrounding Mid-Coast areas are projected to increase from 33.8 in 2020 to 70.8 in 2099 under a lower-end scenario of global emissions (RCP 4.5). The extent of these days will increase more than thrice to 130.6 by 2099 as compared to present conditions under a higher-end emission scenario of RCP 8.5. In Rockport, the number of days with a temperature above 100°F is likely to increase from less than 1% in 2020 to over 16% in 2099 under a higher-end emission scenario. In Matagorda and Jackson counties, the number of extremely hot days when the



temperature rises over 100°F will increase from about one day in 2020 to more than 52 days under a higher-end emission scenario. Figure 12 shows the changes in hot and cold days at the Rockport station.

The data on annual precipitation changes depict more spatial and temporal variations across Texas in the future (Jiang & Yang, 2012). At present, the average yearly precipitation ranges from 30 to 50 inches in the Texas Mid-Coast, with small changes expected in the future (Kloesel et al., 2018). However, the frequency and intensity of extreme precipitation events are expected to increase under a higher-end scenario in the entire Southern Great Plains region, including the Texas coastline (Kloesel et al., 2018; Runkle et al., 2017). Heavy rainfall that accompanies a storm event is also projected to increase. During Harvey, the mid-coast region experienced about 10-20 inches of heavy rainfall in total (Blake & Zelinsky, 2018). As compared to 1981–2000, Emanuel (2017) projected a sixfold increase in hurricane rains for Harvey-like events in Texas by the end of the century.

Sea surface temperature has also been increasing in the Gulf of Mexico and associated estuaries and bays (Hoegh-Guldberg et al., 2014). For this assessment, observed changes in water temperature are based on the point measurements collected by Texas Parks and Wildlife Department for *Water Data for Texas*. The data shows that monthly median temperature in Guadalupe Estuary has increased by about 1.8°F (1°C) between 1990 to 2015 for the months of July to August. Research corroborates that the long-term trends in Lavaca Bay, Matagorda Bay, and San Antonio Bay show a significant increase in summer temperature (Bugica et al., 2020). This assessment does not include projected changes in water temperature but assumes the trend of warming likely to continue in the future for the Mid-Coast estuaries.

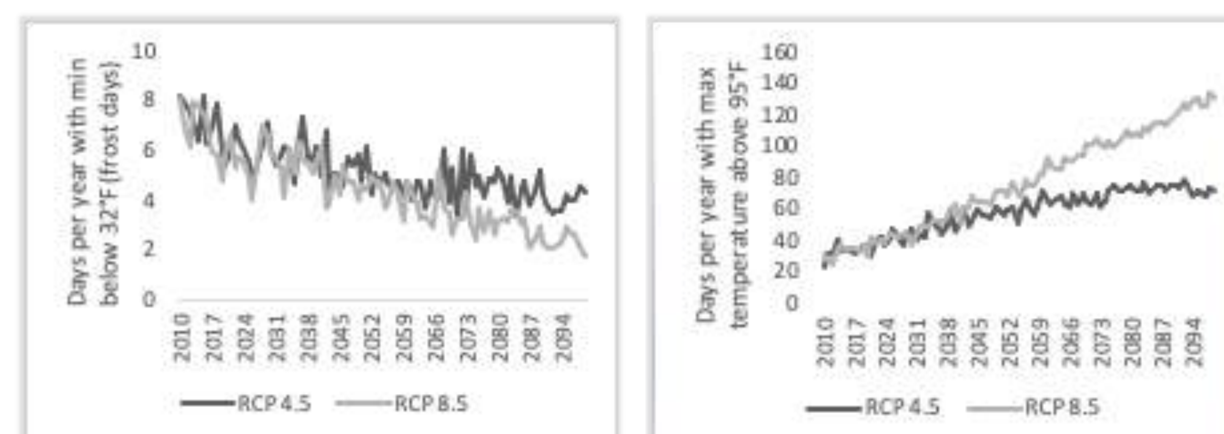



**Figure 12.** Days with min temperature below 32°F (left) and max temperature above 95°F (right).

# ENVIRONMENTAL, SOCIAL, AND ECONOMIC IMPACTS

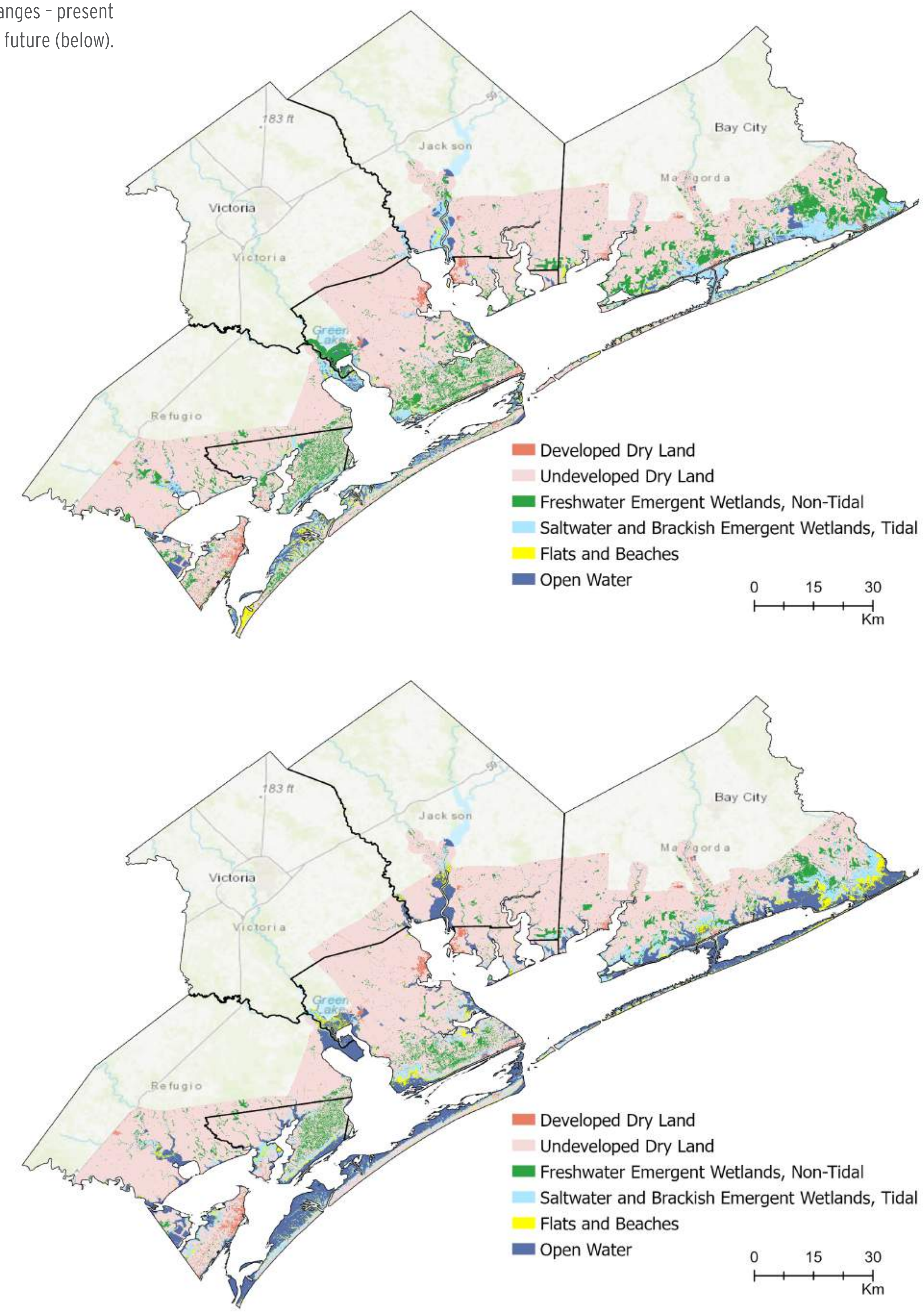
4

This section describes the potential and likely impacts of changing risks from projected climate change and natural hazards to critical resources and assets essential to the local, regional, and state economy, including how they may impact ecosystem services.

## Projected Changes to Coastal Habitats

Climate change-induced sea level rise and storm surge pose direct threats to the ecologically important habitats in the Mid-Coast. The data from NOAA's Office for Coastal Management reveals that wetland cover in Matagorda, Jackson, and Victoria counties has decreased over the last twenty years. However, the decrease has been by less than 1% only. Total wetland area has slightly increased from 1996 to 2016 in other counties ranging from 2.65% for Refugio to 0.86% for Calhoun. However. climate change is likely to accelerate wetland loss in the future at a rate slower than the new wetland area is created. According to the Resiliency Plan, the following habitats within the Guadalupe Bay area are projected to decrease by the year 2100 due to an intermediate (5 feet) increase in relative sea level: estuarine wetlands (-20%), freshwater wetlands (-56%), and undeveloped dry land in surrounding areas (-7%). As much as 21% of the land is expected to be converted to open water by the end of the century. A map showing these changes in land cover types by 2100 is provided below (Figure 13). In the Mid-Coast, wetlands in the NWRs and WMAs are projected to be lost and converted to open water by an intermediate sea level rise scenario.

**Figure 13.**
Land use changes – present (above) and future (below).





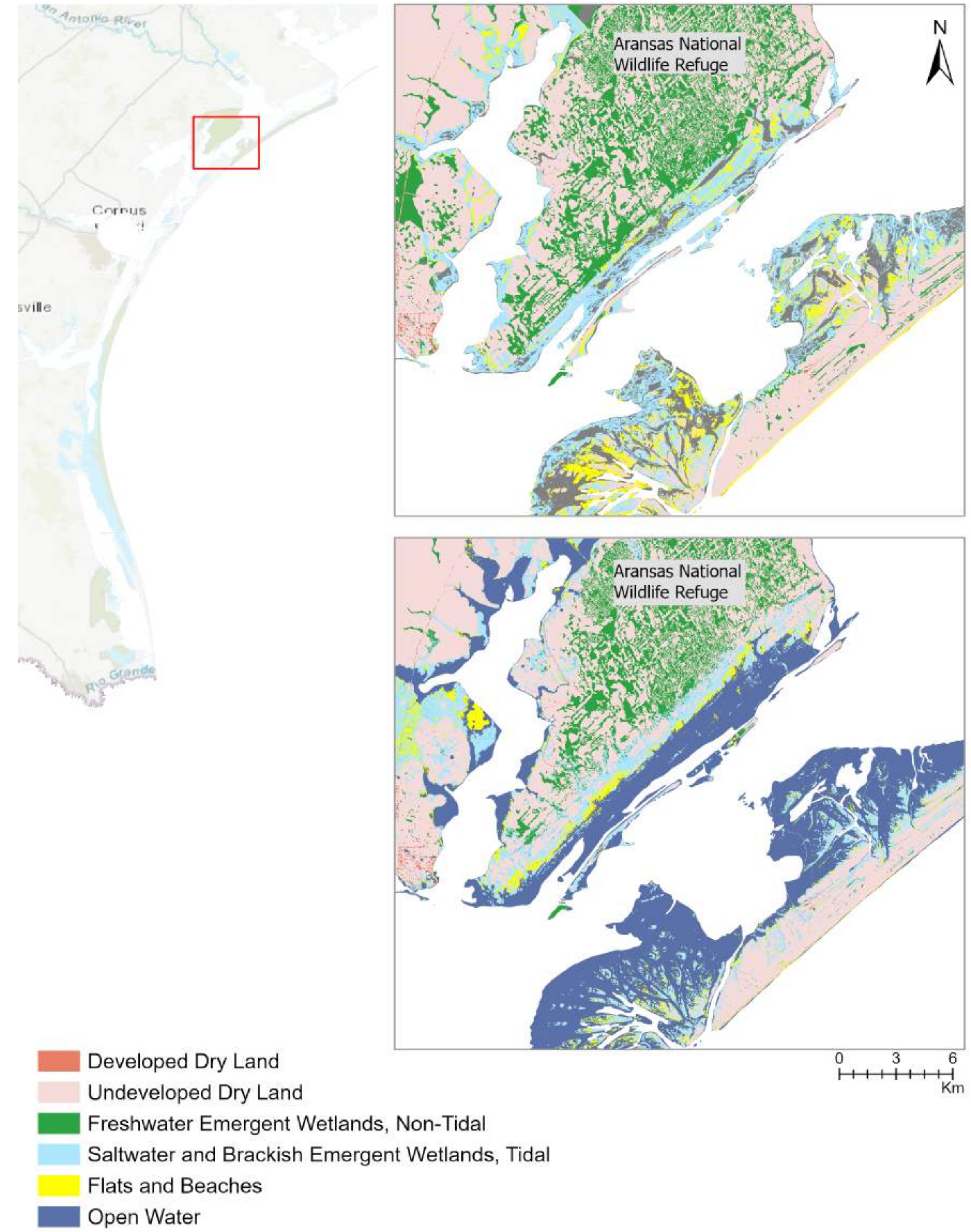




**Figure 14.**
Land use changes in Aransas NWR – present (above) and future (below).

Figure 14 depicts the close-up views of future land use changes in Aransas NWR and the surrounding areas of San Jose and Matagorda Islands due to an intermediate sea level rise (5 feet). The near coast saltwater and brackish wetlands will transition to open water by the year 2100. Most of the tidal wetlands in the barrier islands of Aransas NWR are expected to erode and convert to open water. These estuarine habitats provide storm surge buffers, and their loss through erosion and transition to open water will further increase the severity of future storm surge and sea level rise in the Mid-Coast.

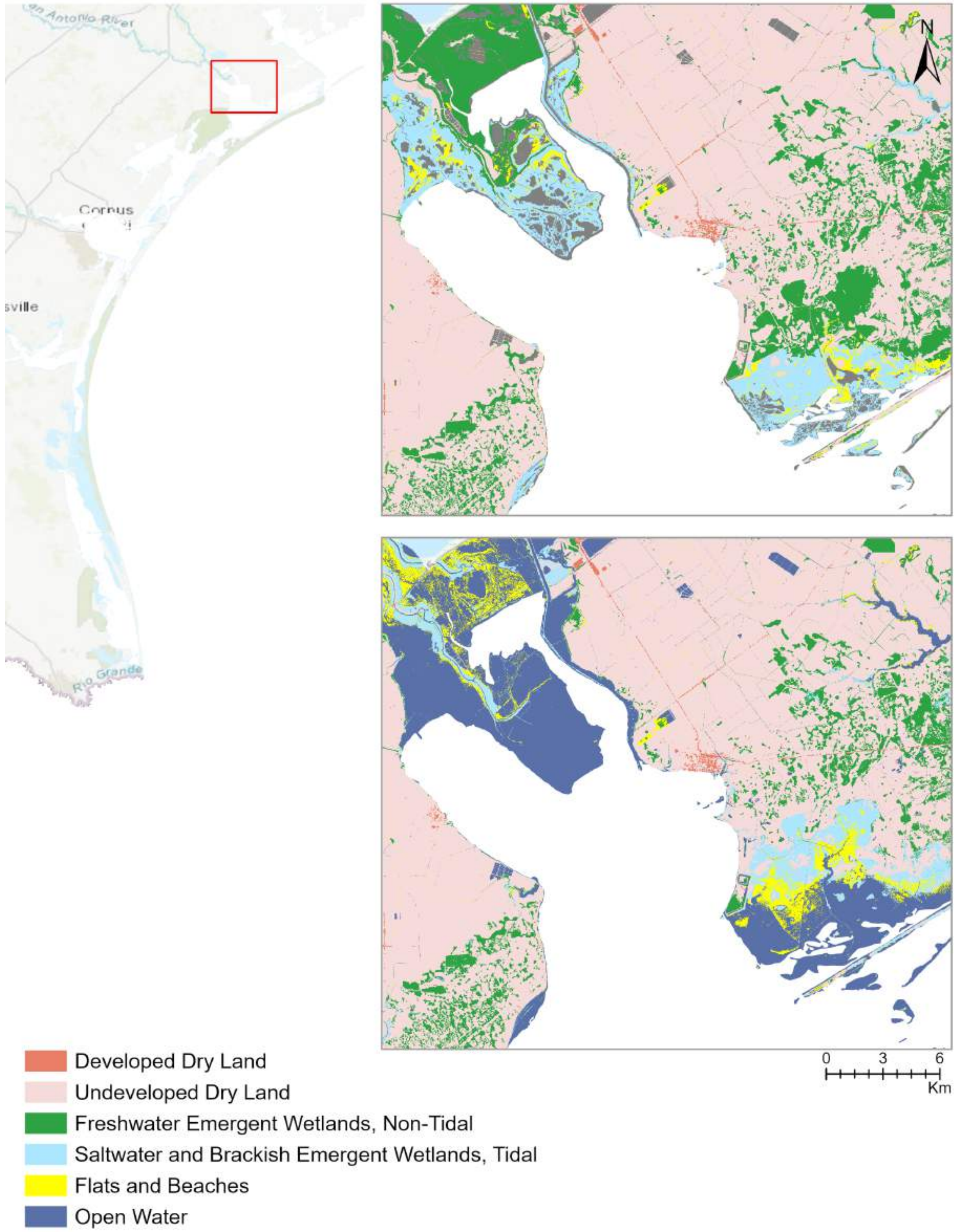



**Figure 15.** Land use changes in Guadalupe Delta WMA – present (above) and future (below).

The changes in land cover for Guadalupe Delta WMA and the surrounding Guadalupe Bay are presented in Figure 15. Around the Guadalupe bay, particularly in some Guadalupe Delta WMA units, almost all the freshwater wetlands will erode to tidal flats or open waters. This decrease in freshwater wetlands, including marshes and swamps, will result in an enhanced saltwater intrusion from the Gulf of Mexico. The current saltwater and brackish wetlands in the Guadalupe bay, with a slower accretion rate than the rise in sea level and lack of options to migrate inward, are likely to convert into open water.



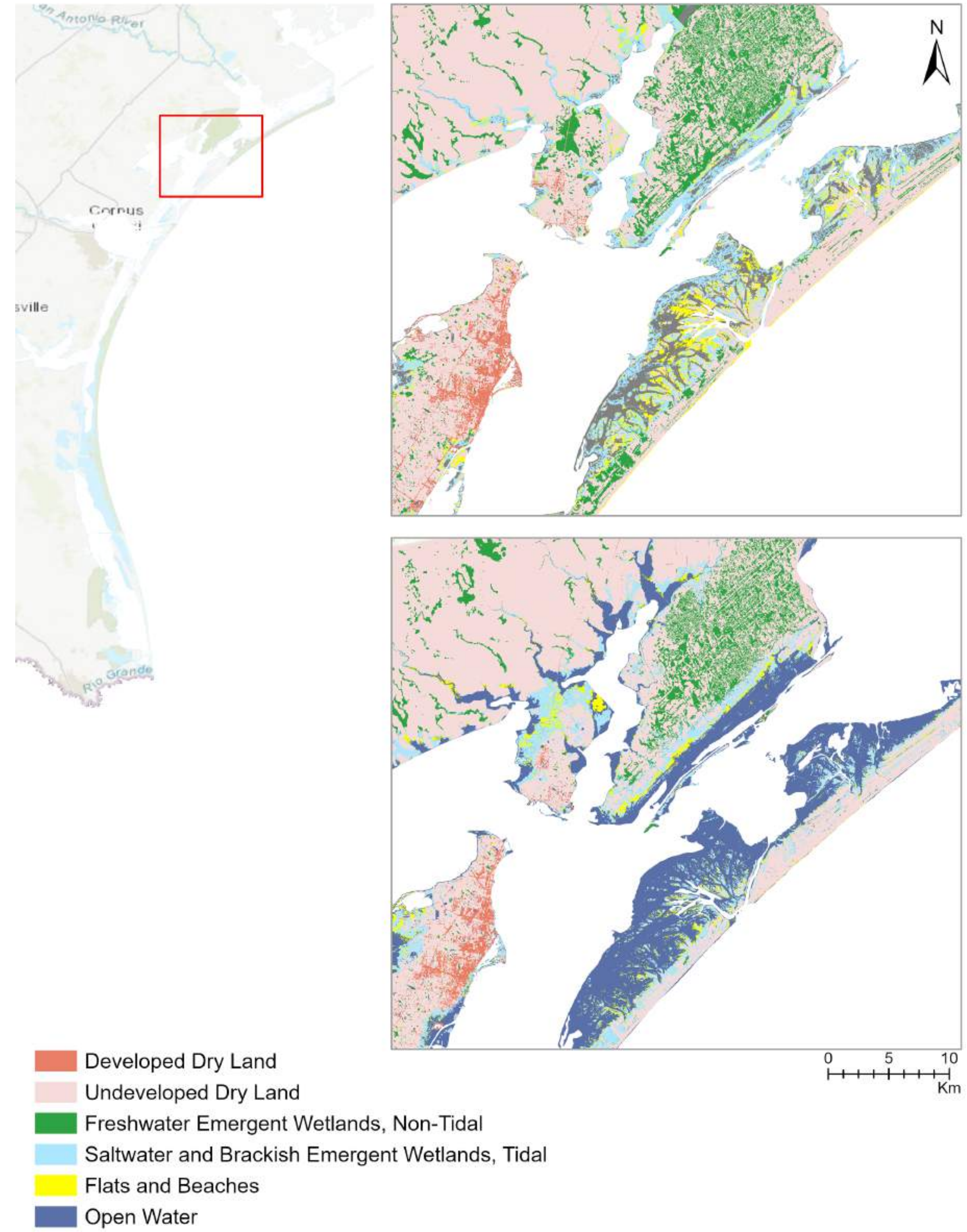



**Figure 16.** Land use changes in Matagorda Bay – present (above) and future (below).

Figure 16 depicts the present and future landcover in the critical areas around Matagorda Bay, such as Big Boggy NWR, Mad Island WMA, etc. In east Matagorda Bay that surrounds the Big Boggy NWR, much of the saltwater wetlands will be lost due to open water. The freshwater wetlands located in the parts of San Bernard NWR will be replaced by flat shorelines and beaches. Similarly, saltwater wetlands in Mad Island WMA and surrounding freshwater wetlands will convert to open water and flat shorelines, respectively.

The changes in temperature and precipitation also poses consequences for the wetlands in the region. Even small declines in the occurrence of extreme winter lows can cause dramatic changes to the ecosystem structure and function of wetlands (Osland et al., 2016). One such threat is the displacement of salt marshes by inland mangroves. Findings from a study indicated an increase in the mangrove extent from 1990 to 2010 around the Harbor Island/Port Aransas/Mustang Island area due to displacement from salt marsh and other wetlands (Armitage et al., 2015). Precipitation can also cause changes to the existing water balance of wetlands. An increase in flashier precipitation will increase the length and depth of flooding for inland wetlands, particularly the smaller wetlands in the region (Finlayson, 2018).

This loss of wetlands and increased open water is likely to cause cascading impacts due to their loss of flood buffer capacity and erosion control to the nearby coastal communities of the Mid-Coast counties. Assuming a loss of 21% and 12% for freshwater and saltwater marshes respective, research conducted in Galveston Bay found annual losses up to $51 million from an initial condition to 2100 (Yoskowitz et al., 2017). This research did not include socio-economic pressures that lead to the loss of wetlands due to coastal squeeze and further add to these monetary losses in ecosystem services.

## Implications for Whooping Cranes and Other Wildlife Species

The wetlands in the Mid-Coast provide crucial nursery habitat for several species, and the loss will be consequential for these birds and animals. Whooping cranes are one such example that winter in the wetlands of Aransas NWR after migrating more than 3,000 miles from Canada. From fewer than 20 birds in 1941, the 2019-2020 winter marked more than 500 whooping cranes at Aransas NWR. Unfortunately, the rising sea level not only threatens the coastal wetlands habitat of whooping cranes, but the declining freshwater lens is also unable to support their primary food source – blue crabs. The freshwater availability is also impacted by other weather patterns such as droughts and upstream water use from the Guadalupe-San Antonio River basin. Nearly 10% of the population died in the winter of 2008-09 due to the unrestricted use of upstream waters during a drought (International Crane Foundation, 2021). Whooping cranes will also be exposed to threats from predators as they fly to upland areas in search of freshwater.

To further support their population expansion, The International Crane Foundation established a habitat goal requiring 50,000 acres of coastal prairie and marsh to become suitable for whooping crane habitat. These acres constitute 25 percent of their long-term target of 200,000 acres of coastal prairies for Whooping crane habitat to accommodate sea level rise and climate change models by 2024 (International Crane Foundation, 2021). A recent article modeled the population growth of whooping cranes under different climate change scenarios and concluded that an urgent timeframe (within the next 30 years) is required to tackle climate change challenges for these birds (Butler et al., 2017).

Migratory waterfowl are dependent on the marshes of Big Boggy NWR, Guadalupe WMA, and Mad Island WMA. Other wetland species such as reddish egret, and white-faced Ibis will be impacted due to loss of foraging grounds at Guadalupe WMA and Mad Island WMA. Loss of saltwater wetlands at Big Boggy NWR will also lead to disruptions in birding and nesting sites for thousands of ducks and geese. In addition to land loss, the location of the Mid-Coast in an ecological transition zone means that even small macroclimatic changes in winter temperature and rainfall can lead to regime shifts in these wetlands and their native vegetation (Osland et al., 2016).

An increase in extreme temperature directly threatens and alters several species. While evaluating all these impacts are beyond the scope of this work, one notable example of Kemp's ridley sea turtles is discussed here. The temperature plays an important role in determining the sex of hatchlings for these endangered sea turtles. Higher temperatures can lead to a low nest success and affect sex ratios with producing only females.

# Projected Changes to Water Quantity and Quality

Freshwater inflow is a growing concern for the Texas Mid-Coast region. At present, data from The Texas Water Explorer, The Nature Conservancy, depicted a declining trend in the 7-day minimum flows for the majority of the streamflow gauges analyzed in Colorado, Guadalupe, Lavaca, and San Antonio River basins over the last two decades. The 7-Day Minimum Flows represent the low streamflow conditions in Texas rivers. Additionally, the water quality assessment of the Guadalupe River basin conducted by the Texas Commission on Environmental Quality showed 32% of the 1,233 km segments with impaired water quality. For Colorado and Lavaca River basins, the data from assessment revealed impaired water quality for 22% of 3208 km segments and 24% of 387 km segments, respectively. The findings were even more daunting for the San Antonio River basin, with 70% of the 918 km having impaired water quality.

Changes in land use and population will also impact freshwater availability across the Mid-Coast. According to The Texas Water Explorer, 96% of the Lavaca River basin are vulnerable to general land clearing for irrigation purposes. For San Antonio River basin, 60% of the 1,471 km of rivers and streams are considered highly vulnerable to urbanization, 28% from impacts of general land clearing, and 3% from impacts of row crop agriculture. This increase in the population upstream means less freshwater availability to the Mid-Coast counties.

The changes in freshwater inflows from upstream rivers will impact the estuaries and bays in the Mid-Coast region. A recent study found an increase in the salinity of Mid-Coast estuaries in Texas due to decreasing freshwater inflow (Bugica et al., 2020). Long-term water quality trends in Matagorda Bay and Lavaca Bay indicate an increase in salinity by an average 0.3/year in the last 20 years (Bugica et al., 2020). The future freshwater inflows will be further impacted by increasing demand upstream and climate variability induced by temperature and precipitation extremes. Under a future scenario of temperature increase by 3.6°F (2°C) and a 5% decrease in precipitation, the entire central Texas coast is expected to witness a 36% decrease in the downstream flow by 2050 (Ward, 2011). When severe droughts and population growth are added to this future climate projections, the freshwater flow to the coast is projected to decrease as much as 74% as compared to the baseline 2000 levels (Ward, 2011). These projections are significant and demonstrate the compound impacts of climate change on future freshwater inflows. For example, Ward (2011) projected only a 5% decrease in the downstream flows based solely on population growth which increases considerably when climate change projections are added. The last ten years have not witnessed any dent in the temperature or population growth, making the decrease in flows more alarming than the ones projected by Ward in 2011.

Storm surge also plays a central role in disrupting the water quality and aquatic ecosystems. During Hurricane Harvey, the Guadalupe Estuary experienced an increase in salinity and low dissolved oxygen levels; however, these changes were short-lived (Walker et al., 2020). Nevertheless, these sudden changes in water quality combined with wind and wave surge can potentially harm the aquatic life that takes refuge in the estuary.



# Impacts on Key Economic Sectors

## CRITICAL FACILITIES

Sea level rise will result in the inundation of several coastal facilities. A dataset containing shapefiles of College/University, Fire Station/EMS Station, Law Enforcement, Prison/Correctional Facility, State Capitol, Hospital/Medical Center, Ambulance Services, Cemetery, and Post Office was downloaded from USGS and overlaid with the inundation zones for intermediate low, intermediate and intermediate high sea level rise scenario. A detailed methodology is provided in Appendix B. The analysis indicated that 44 critical facilities across the Mid-Coast, including city halls and police departments in Rockport and Port Aransas, are at risk of permanent inundation by the intermediate low sea level rise estimates. In Matagorda, Matagorda post office, volunteer fire department, and emergency medical services are threatened by an intermediate low sea level rise. A 3 feet increase in sea level rise will also lead to permanent inundation of sites with cultural importance, such as Indianola and Zimmerman Cemeteries in Port Lavaca, Calhoun. In the event of worst-case projections of sea level rise, these risks to infrastructure significantly increase, from 44 to 199 facilities at risk. In the towns of Fulton, Port Aransas, Rockport, and Seadrift, the impact of inundation on critical facilities will be consequential to the resilience of coastal communities. For example, Fulton's fire department, town hall, post office, and police department are vulnerable to an increase in sea level rise by 7 feet. In Palacios, school systems, including central elementary school, Palacios junior high school, and Palacios high school, are at risk of inundation by intermediate high sea level rise scenario. Other at-risk areas include culturally significant sites in the city, such as Ashby cemetery, Palacios cemetery, and seaside memorial park. The absence of these essential services will have far-reaching consequences on these towns' functioning and future existence.

## FISHERIES

The changes in water quality and reductions in freshwater flows delivered from the Guadalupe-San Antonio River basin and Colorado-Lavaca River basin can adversely impact and disrupt commercial and recreational fisheries in the Mid-Coast estuaries. Some of the most widely occurring fishes in the Guadalupe Bay and Matagorda Bay are Black Drum Pogonias cromis, Red Drum Sciaenops ocellatus, Southern Flounder Paralichthys lethostigma, and Spotted Seatrout Cynoscion nebulosus. An example of temperature and salinity ranges for Southern Flounder and Spotted Seatrout is provided in the table below (Table 1). Changes in water temperature and salinity negatively impact the fish population, their spawning rates and distribution. For example, a recent study in Texas found that Southern Flounder are more vulnerable to winter temperature extremes than Red Drum and Spotted Seatrout as their spawning time is more restricted (McDonald et al., 2016). Another study analyzing the distribution of 150 species across the coast of Texas found a decrease in occupancy probability of Southern Flounder with salinity and sea level rise as primary drivers (Fujiwara et al., 2019). The researchers also found a northward shift and expansion in the range of many species for suitable environmental conditions that indicate a future change in existing fisheries composition for the Mid-Coast.

**Table 1.** Examples of optimum temperature and salinity ranges for two common estuary-dependent fishes in the Mid-Coast.

| Common Name | Scientific Name | Temperature Range (°F) | Salinity Range (ppt) | Reference |
|---|---|---|---|---|
| Southern Flounder | P. lethostigma | 41-95 | 0-10 | Hendrickson & Cohen, 2015; Nims, 2012 |
| Spotted Seatrout | C. nebulosus | 59-86 | 10-20 | Froeschke & Froeschke, 2011; TinHan et al., 2018 |

In 2011, reduced freshwater inflows resulted in high salinities and red tide events in Texas estuaries across the entire coast. The red tide was accounted for killing 4.4 million fish and contaminating oysters inducing economic losses of up to $7.5 million due to the closure of commercial oyster season (Loeffler, 2015). In addition to salinity, changes in temperature may alter the growth of other estuarine-dependent species. For example, the increase in temperature is consequential for the juvenile blue crabs that reach maturity faster in higher temperatures although remaining smaller in size (Cunningham & Darnell, 2015). This may lead to shorter life spans for juvenile blue crabs with implications for the whooping crane population. Higher sea surface temperatures and salinity are also correlated with higher concentrations of pathogenic Vibrio species in coastal estuaries and associated shellfish, particularly oysters, which, when ingested, leads to human health risks (Froelich & Daines, 2020). In 2014, about 26% of the total vibriosis cases in the US were reported from the Gulf Coast states, with 75 cases from Texas (CDC, 2014).

Additionally, the oceans increased absorption of high levels of anthropogenic atmospheric $CO_2$ leads to increased inorganic carbon concentrations and results in decreased water pH and calcium carbonate saturation, more commonly known as ocean acidification. This climate change-induced phenomenon has been shown to result in severe impacts on the food web base like corals, echinoderms, mollusks, crustaceans, and larval fishes (Wittmann & Pörtner, 2013). Decreased productivity and population health of these key species at the base of the food web can have vast impacts on most other valuable higher-level commercially and recreationally important fish, bird and marine mammal species.

## ECOTOURISM

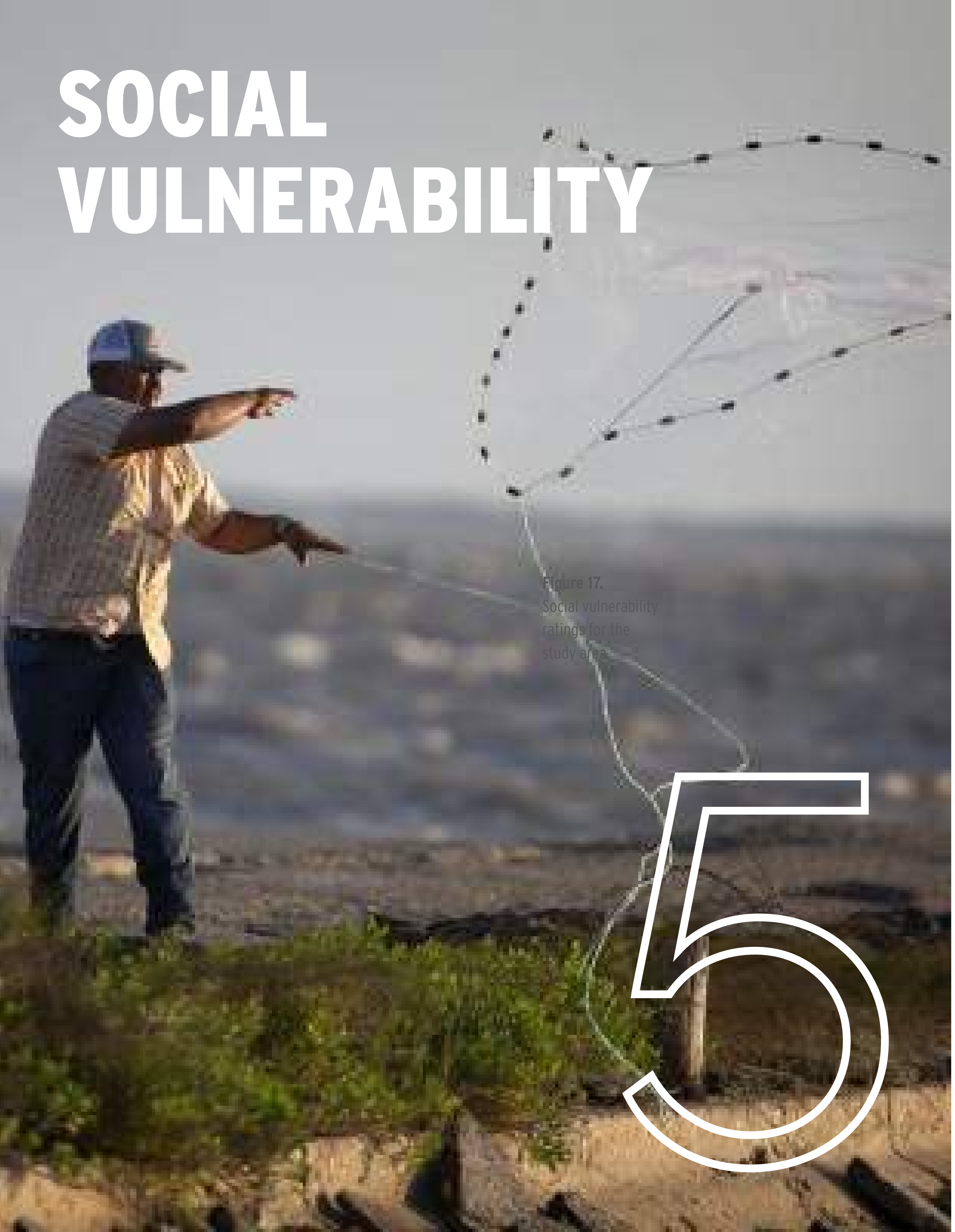
The outdoor economy is vital to Texas. In 2019, outdoor recreational activities such as camping, hiking, hunting, boating, and fishing, generated more than $35 billion in revenue and provided employment to 327,281 individuals in Texas. The state, in fact, ranked third in the country for the contribution of outdoor recreation to its GDP and jobs. Teeming with wildlife and abundant ecosystems, nature-based tourism is even more crucial to the economy of the Mid-Coast. According to the Outdoor Industry Association, residents in the 27th congressional district that spans across the counties of Aransas, Calhoun, Jackson, Matagorda, Refugio, and Victoria, spend $1.29 billion on outdoor recreation each year, with fishing, camping, and water sports as the most popular activities.

The analysis conducted for this assessment revealed several ecotourism sites and WMAs are vulnerable to storm surge and a future increase in sea level rise. For instance, Goose Island State Park that covers 321 acres and attracted over 190,000 visitors annually for hiking, camping, and fishing, will be prone to damages by a weak Category 2 storm surge combined with an intermediate low estimate of sea level rise in the future. The Calhoun loop of the Great Texas Coastal Birding Trail, where visitors flock for birdwatching, will be disconnected due to inundation by sea level rise at Matagorda Island WMA. Matagorda Bay Nature Park is susceptible to an intermediate sea level rise, whereas Matagorda beach will be completely lost by an intermediate sea level rise.

The Guadalupe Delta WMA, Mad Island WMA, Aransas NWR, Big Boggy NWR are at risk of potential inundation in the future. These sites provide hunting, birdwatching and other recreational opportunities to Texans. Other tourism infrastructure such as the Mustang Beach Airport and Aransas County Airport are also susceptible to inundation by a low to intermediate estimate of sea level rise, respectively. Several visitors travel to these areas generating tourism revenue for local counties and their communities. In 2017, Aransas NWR witnessed about 84,000 visitors, with 72% non-residents, accounting for a total expenditure of $2.5 million on activities related to wildlife photography, auto tour, visitor center, etc. (FWS, 2019). The tourism in the NWR also provided economic opportunities to the local communities of Aransas, Calhoun, and Refugio counties through generating 25 jobs, $783,000 in employment income, $244,000 in total tax revenue, and $3.0 million in economic output (FWS, 2019).

Additionally, tourism also contributes to the state and local tax revenue through sales, hotel occupancy, etc., thereby supporting other vital public sector jobs. The six counties combined accounted for about $480 million in visitor spending and added more than $40 million to Texas' state tax generated by travel spending (Travel Texas, 2019). Even an intermediate low scenario of sea level rise threatens tourism attractions in the Mid-Coast region. These include Rockport beach and fishing pier and disruption of several other sites at the Great Texas Coastal Birding Trail loop. In case of higher estimates of sea level rise, risks to coastal towns of Port O'Connor, Port Lavaca, Seadrift, and Palacios will significantly while simultaneously eroding their recreational opportunities. For instance, Port Lavaca's Magnolia beach, one of the only natural shell beach on the Gulf Coast, and the Indianola Fishing Marina will be prone to inundation by an intermediate high increase in sea level rise. In addition to direct threats, indirect impacts to tourism due to loss of fisheries, wetlands, and associated wildlife will also result in the loss of tourism-related revenues in the future. With the future risks to the physical and natural infrastructure vital for tourism and the central role of the sector to their local communities and counties, climate change impacts here will evidently pose spillover socio-economic implications to the entire state.

# SOCIAL VULNERABILITY



5

Social vulnerability is defined as the susceptibility of social groups to the adverse impacts of natural hazards. According to the Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) data, the current social vulnerability in Aransas, Matagorda, and Refugio counties is relatively high, whereas it is relatively moderate in Calhoun, Jackson, and Victoria counties. NRI uses Social Vulnerability Index (SoVI) based on 29 socioeconomic variables such as ethnic population, per capita income, health insurance, etc., that reduce a community's ability to deal with hazards. A detailed census tract rating of social vulnerability for our study area is depicted in Figure 17. The ratings describe a community's social vulnerability score in relation to all other communities in the state.

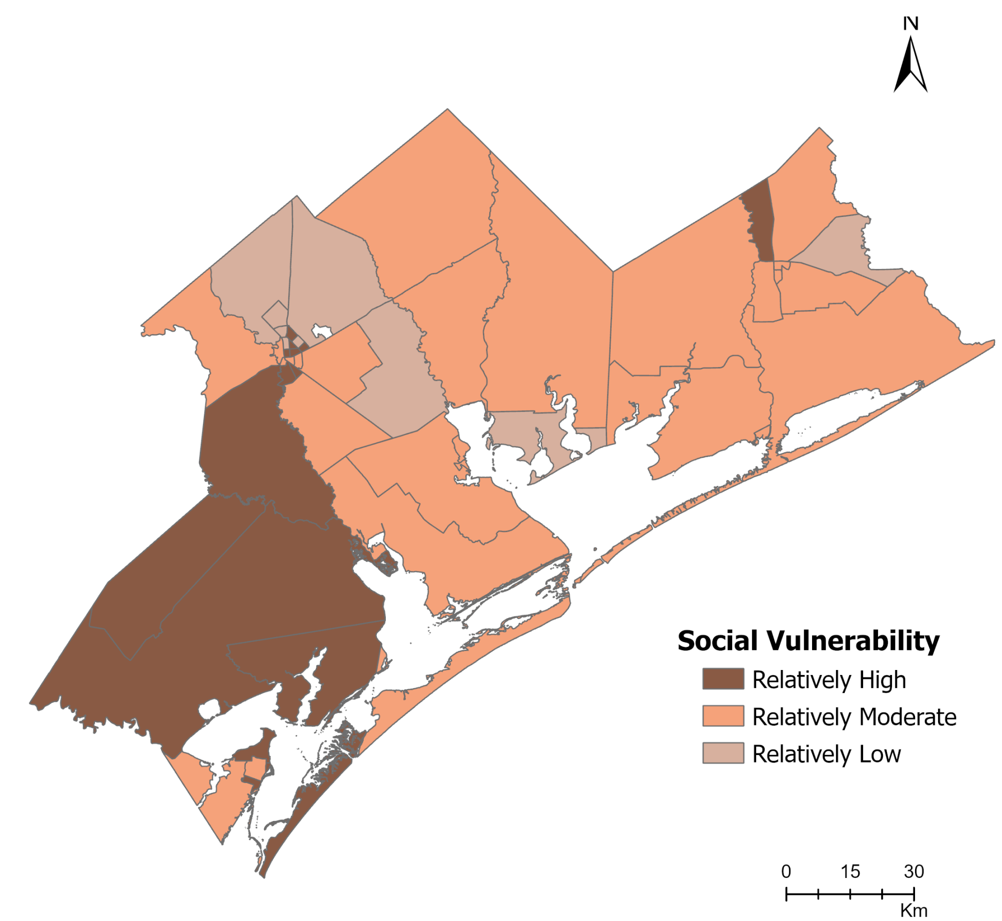



**Figure 17.** Social vulnerability rating for the study area.

## Population Changes

According to the Resiliency Plan, the coastal population was 6.7 million as of 2019. It is expected to increase to 10 million or more by 2050, a 49% increase over the next 30 years. Except for slight decrease in Matagorda and Refugio, the other Mid-Coast counties will experience an increase in population, with Aransas and Victoria witnessing the highest growth (Table 2). The total population will increase by more than 24% in the four counties. The Texas Demographic Center projections show that the population of Hispanic ethnicities will surpass the non-Hispanic white population by 2020, growing over 20 million by 2050. The non-Hispanic black population is expected to double with a size of 6 million by 2050. The population increase trend of Hispanic and Non-Hispanic black across most of the Mid-Coast counties is consistent with Texas's statewide increase. The population increase of

Hispanic and Black people will be highest in Aransas County. In Matagorda and Refugio counties, where the population already shows a declining trend, the number of Black people will decline by mid-century.

Expansion of population will also enhance the vulnerabilities posed by climate variability and extreme events. An increasing population directly corresponds to a higher number of people at risk during extreme events. A study conducted across the US coastal counties, including the Texas Mid-Coast counties, found that the combined effects on climate change and coastal development will cause an increase in hurricane damage in the future (Dinan, 2017). In another study conducted after Hurricane Harvey, urbanization was found to increase the probability of extreme flood events and precipitation by about 21 times during the hurricane event (Zhang et al., 2018). Increasing coastal population and the following development will magnify the future risks of climate change by exerting pressure on existing coastal resources. More coastal development in rural Mid-Coast areas will affect the existing coastal habitats leading to habitat encroachment in the region.

**Table 2.** Current and future population projections.

| | Total (2020) | Total (2050) | Hispanic (2020) | Hispanic (2050) | Percent change | Non-Hispanic black (2020) | Non-Hispanic black (2050) | Percent change |
|---|---|---|---|---|---|---|---|---|
| Aransas | 27699 | 46239 | 8331 | 22472 | 170 | 298 | 387 | 30 |
| Calhoun | 22840 | 23939 | 11522 | 14216 | 23 | 596 | 617 | 4 |
| Jackson | 15899 | 22877 | 5693 | 12583 | 121 | 1054 | 1106 | 5 |
| Matagorda | 37064 | 33307 | 15752 | 17272 | 10 | 3962 | 3708 | -6 |
| Refugio | 7573 | 7570 | 4009 | 4915 | 23 | 484 | 414 | -14 |
| Victoria | 97744 | 125663 | 46751 | 72133 | 54 | 5873 | 7001 | 19 |

*Based on data available from Texas Demographic Center, 2019*

In their pioneering work, Cutter et al. (2003) indicated that race and ethnicity play a central role in increasing social vulnerability due to factors such as language barriers and residential locations in high hazard areas. Numerous studies support the elevated risk of climate change to racial and ethnic minorities of Hispanic and Black due to existing income and social well-being gaps (Hardy & Hauer, 2018; Shepherd & KC, 2015). In a study conducted by Hardy and Hauer (2018) in coastal Georgia, the Hispanic population's exposure to sea level rise increased the largest under a mid to high estimate. The findings concluded that the absolute magnitude of climate change impacts will increase on socially vulnerable population in the future (Hardy & Hauer, 2018). Table 2 shows a positive trend in the population of Hispanic and Non-Hispanic Black people in four out of six Mid-Coast counties. With a future increase in the population of these socially vulnerable groups, it is likely that the extent of social vulnerability will further increase in the future.

# Additional Social Vulnerability Considerations

Several other factors that add to the social vulnerability of the Mid-Coast counties are provided in Table 3 (U.S. Department of Commerce, 2020). These include a high percent of the population over 65, percent of housing with mobile homes, and percent of the population with disabilities in the region. For instance, the six counties combined have more than 13% of housing that are mobile homes, with the highest share of such homes in Aransas County (19.3%). This is significantly higher as compared to the national average of 5.5%. During Hurricane Harvey, several of the mobile homes in Seadrift faced consequential damages. The counties also constitute a high percentage of people without health insurance (17.6%) as compared to the US average (8.8%) (U.S. Department of Commerce, 2020). These factors further lower the resilience and adaptive capacity of communities in the face of future conditions.

**Table 3.** Social vulnerability indicators.

| Indicators | Combined Counties* | United States |
|---|---|---|
| Percent of Population under 5 | 6.7% | 6.1% |
| Percent of Population over 65 | 17.9% | 15.6% |
| Percent of Population Non-White (all other races) | 16.2% | 27.5% |
| Percent of Population Hispanic | 43.0% | 18.0% |
| Percent of Population without a High School Diploma | 17.4% | 12.0% |
| Percent of Population that speak English "Not Well" | 4.0% | 4.3% |
| Percent of Population in "Deep Poverty" | 6.4% | 6.0% |
| Percent of Families Below Poverty | 12.2% | 9.5% |
| Percent of Families that are Single Mother Households and Below Poverty | 4.8% | 4.3% |
| Percent of Households Receiving Food Stamps (SNAP) | 13.3% | 11.7% |
| Percent of Population that "Did Not Work" | 25.0% | 23.2% |
| Percent of Rentals where Gross Rent Exceeds 30% of Household Income | 39.6% | 46.0% |
| Percent of Housing that are Mobile Homes | 13.2% | 5.5% |
| Percent of Households that are Single Female with Children under 18 | 8.0% | 7.8% |
| Percent of Households with No Car | 5.8% | 8.6% |
| Percent of Population over 65 and Living Alone | 45.7% | 33.4% |
| Percent of Population with Disabilities | 16.6% | 12.6% |
| Percent of Population without Health Insurance | 17.6% | 8.8% |

**Aransas, Calhoun, Jackson, Matagorda, Refugio, and Victoria counties*

# ADAPTATION PLANNING


Assessing and mapping existing hazard vulnerabilities lays the foundation for planning and adapting to increasing climate variabilities. This section builds on the previous sections to identify adaptation strategies, specifically nature-based solutions, to lower vulnerabilities and enhance resilience along the Mid-Coast. The focus lies on funding mechanisms and tools that the decision-makers can leverage to adopt these restoration and adaptation strategies.

## Advancing Ecosystem Restoration and Adaptation Goals

There is a great deal of evidence supporting the role of ecosystem restoration and nature-based adaptation in tackling the risks posed by climate change and enhancing coastal resilience. Coastal habitats such as marshes, wetlands, mangroves, coral and oyster reefs reduce the risk of erosion and flooding for coastal communities (Barbier et al., 2011). A recent example comes from Hurricane Irene, during which 76% of the bulkheads were damaged, whereas the hurricane had no impact on the marsh shorelines (Gittman et al., 2014). The co-benefits of these habitats extend to other ecosystem services such as recreation and carbon sequestration while providing a healthy habitat for fisheries and marine life.

Despite the evidence, the importance of coastal ecosystems and ecosystem restoration is yet to be fully tapped in the region. Funds for gray infrastructure projects continue to flow towards coastal planning efforts that not only turn out to be more expensive but may also not be able to keep up with the continuously changing climatic conditions. Despite the existing seawall, the city of Seadrift faced $8 million to $11 million in damage due to Hurricane Harvey. However, the city still intends to funnel about $7 million to repair and extend its seawall (City of Seadrift, 2021). With the future increase in hurricane intensities, compounded threats by sea level rise, rapid growth, and overall growing vulnerability of the Mid-Coast, stronger shifts and financial investment in ecosystem restoration need to be prioritized in this region.

To further help the case for ecosystem restoration and conservation, funds are already allocated for such initiatives at the federal, state, and local levels. 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. Table 4 provides a list of projects in the Mid-Coast focusing on ecosystem restoration pulled from the Deepwater Horizon Project Tracker database. These projects aim to support wildlife species by providing necessary migration, wintering, and breeding habitats for numerous waterfowl, shorebirds, and wading birds.

In addition to the Deepwater Horizon oil spill funding programs, the Resiliency Plan proposes more than 25 projects totaling up to $171 million that prioritizes

**Table 4.**
Examples of projects funded from the Deepwater Horizon Oil Spill.

| Name | Funding Agency/ Implementing Agency | DWH Funding | Year Funded | Brief Description |
|---|---|---|---|---|
| Egery Flats Marsh Restoration | National Fish and Wildlife Foundation (NFWF) / Coastal Bend Bays and Estuaries Program | $1,587,000 | 2014 | Restore hundreds of acres of coastal marsh habitat within Egery Flats |
| Texas Gulf Coast XIII | U.S. Fish and Wildlife Service (USFWS) /Ducks Unlimited, Inc. | $999,846 | 2016 | Restore, and enhance 2,519 acres of wetland habitat on private lands |
| Coastal Texas II | U.S. Fish and Wildlife Service (USFWS) /Ducks Unlimited, Inc. | $999,823 | 2017 | Restoration and enhancement of 1,400 acres of privately-owned wetlands |
| Coastal Texas III | U.S. Fish and Wildlife Service (USFWS) /Ducks Unlimited, Inc. | $989,790 | 2018 | Restore and enhance 2,730 acres of decreasing coastal wetland types and other critical habitats |
| East Matagorda Bay Land Conservation | National Fish and Wildlife Foundation (NFWF)/ Texas Agricultural Land Trust | $3,981,500 | 2018 | Conserve 3,547 acres of coastal working lands in the Mid Coast through a perpetual conservation easement |
| Port Aransas Nature Preserve Debris Removal | National Fish and Wildlife Foundation (NFWF)/Port Aransas City | $100,000 | 2018 | Restore essential coastal wetland habitat at the Leonabelle Turnbull Birding Center within the Port Aransas Nature Preserve |
| Enhancement of Buffalo Lake Marsh Complex | National Fish and Wildlife Foundation (NFWF)/ Texas Parks and Wildlife Department (TPWD) | $450,000 | 2019 | Enhance freshwater wetland habitats on the landscape to support migratory waterfowl, shorebirds, and waterbirds |
| Carancahua Bay Habitat Preservation and Enhancement - Phase II | National Fish and Wildlife Foundation (NFWF)/ Texas General Land Office | $6,100,000 | 2020 | Construction of a 2-mile living shoreline to protect and restore the mouth of Carancahua Bay |
| Mid-Coast Habitat Acquisition | Natural Resource Damage Assessment Trustees (NRDA)/State of Texas | $3,252,398 | N/A | Acquisition of 800 acres, including 555 acres of mostly estuarine wetlands as part of the Texas Mid-Coast National Wildlife Refuge Complex in Matagorda County |

*Based on the data available on the Deepwater Horizon Tracker website*



ecosystem conservation and restoration in the Mid-Coast. In Matagorda Bay, some proposed projects place emphasis on oyster reef restoration and habitat restoration efforts in Rookery Island, Coon Island, and Lavaca Bay. Several projects in the Master Plan, such as Aransas National Wildlife Refuge Dagger Point Shoreline Preservation and Welder Flats WMA, put forward the use of living shorelines. In the Guadalupe Delta, the projects – Guadalupe Delta Estuary Restoration and Guadalupe River and Delta Wildlife Management Area Acquisition – are intended to create living shorelines and acquire additional land within the river and WMA to ensure wetland protection and freshwater inflow, respectively. Several other projects in the Resiliency Plan, such as Goose Island State Park Habitat Restoration and Protection, and Fulton Beach Road Protection, among others, propose living shorelines to deal with shoreline erosion of critical habitat.

There are several other funding opportunities available for nature-based adaptation. Some of these grants available from federal programs and state agencies are listed below (Table 5). Allocating funds to these natural infrastructure projects yield high benefit-to-cost ratios. In a study evaluating the cost-effectiveness of different adaptation measures in the face of climate change, land subsidence, and coastal development across the Gulf, nature-based solutions provided average benefit to cost ratios above 3.5 (Reguero et al., 2018). Wetland restoration and oyster reef restoration were found to be most effective, with high benefit-to-cost ratios of 8.7 and 7.3 times in risk reduction benefits for every dollar spent on restoration, respectively (Reguero et al., 2018).

# Adaptation Assessment Tools and Resources

To further advance adaptation goals, local leaders, decision-makers, and coastal resource managers can utilize a range of coastal adaptation strategies that are available as tools to mitigate adverse environmental and socio-economic impacts from changing risks. The following is a list of some of these resources and toolkits:

US Climate Resilience Toolkit: This toolkit is an inter-agency initiative of the United States Global Change Research Program. It provides a compilation of tools and case studies to evaluate vulnerability and adaptation strategies for potential climate hazards. Some examples include "Coastal Resilience Resource List" which provides a comprehensive list of coastal resilience projects in the Gulf and "Coastal and Waterfront SmartGrowth" which offers smart growth principles for building coastal and waterfront-specific development.

Adaptation Resource Center (ARC-X)**:** Developed by EPA, this resource allows creating a tailored assessment of climate risks and adaptation strategies based on the area of interest.

Adaptation Strategies: As part of their Digital Coast resources, NOAA provides a combination of training modules, publication guides and references for coastal officials to create or improve adaptation strategies. Courses such as Nature-Based Solutions for Coastal Hazards are offered to help coastal managers plan and implement natural infrastructure projects.

[Coastal Resilience Tools]: An initiative created by public-private partnership between The Nature Conservancy, USGS, NOAA, and others, it includes various mapping tools for identifying and evaluating adaptation options. Some examples that cover the Mid-Coast geography include – Economics of Coastal Adaptation tool that allows users to compare the cost-effectiveness of green and gray infrastructure, Natural Defense Projects tool that provides an overview of coastal habitats such as mangroves and marshes, and Restoration Explorer tool that allows to identify potential living shoreline techniques to protect against flooding and erosion.

[Strategic Conservation Assessment Tools]: These tools are a collaborative project called The Strategic Conservation Assessment of Gulf Coast Landscapes funded by the Gulf Coast Ecosystem Restoration (RESTORE) Council. The three planning tools include an inventory of local conservation plans and priorities, assessment of co-benefits of these plans and visualization of the data based on the selected parameters of conservation priorities.

**Table 5.**
Examples of major federal and state level funding opportunities for nature-based projects.

| | Name | Funding Agency | Brief Description |
|---|---|---|---|
| Federal | Community-Based Restoration Program | NOAA | Wetlands, coral reef restoration, and bivalve shellfish habitat restoration |
| | National Coastal Resilience Fund | NOAA | Living shoreline, floodplain-habitat restoration design, marsh and wetland habitat restoration |
| | Hazard Mitigation Assistance | DHS - FEMA | Drought and flood risk reduction projects, such as aquifer storage and recovery, floodplain and stream restoration |
| | Building Resilient Infrastructure and Communities (BRIC) grant program | FEMA | Hazard mitigation planning, conventional and nature-based infrastructure, and research-oriented, proactive investment in community resilience |
| | Community Development Block Grant Disaster Recovery (CDBG-DR) grants | HUD | Disaster relief and recovery, infrastructure restoration and economic revitalization |
| | Section 319 Nonpoint Source Management Program | US EPA | Nature-based solutions demonstration projects related to water quality improvements |
| State | Gulf of Mexico Energy Security Act | BOEM/GLO | Coastal projects targeting the restoration of coastal damage from Hurricane's 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 |

# FUTURE ACTION AND POLICY RECOMMENDATIONS


This assessment distilled the larger context of coastal risks down to a localized understanding of the Mid-Coast region's exposure for present and future risks posed by climate change. The key takeaway is that the Texas Mid-Coast is highly vulnerable to storms, sea level rise, and changes in extreme winter temperatures and rainfall regimes. Combined with increasing coastal development and population, these risks will have cascading impacts on coastal and marine ecosystems such as fisheries, wetlands, and other wildlife species of the region. This will cause spillover socio-economic implications to the surrounding coastal communities who are dependent on recreational, functional, and cultural benefits derived from these ecosystems.

Building political consensus, planning, and finance takes time. Following a catastrophic 1953 storm, it took both the Netherlands and England almost 30 years to complete resilient infrastructure projects (Oppenheimer & Alley, 2016). In the Mid-Coast, there is no time to wait-and-see for decision-makers, and specific adaptation measures are the need of the hour. This section outlines policy recommendations on future restoration and adaptation strategies to address the adverse impacts and associated implications to critical natural and economic assets.

## Conserve and restore wetlands to safeguard whooping cranes and other coastal species to maintain Texas' coastal heritage of recreation and a vibrant seafood industry by:

- Investing in strategic coastal land acquisitions, expansion, and ecosystem restoration priorities for critical NWRs and WMAs identified in the region, leveraging Deepwater Horizon oil spill and state and federal funding programs identified above. This includes coordination with partner agencies and private landowners to protect vulnerable wetlands on both public and private lands.
- Working with conservation planners, wildlife biologists, and resource managers to protect winter habitat for whooping cranes. This includes creating incentives for private landowners to provide habitat for the protection of vulnerable and endangered species on their land.
- Implementing living shoreline techniques to reduce the intrusion of saltwater along the bay and protect wetlands, refuge systems, protected areas as well as improve water quality.

## Ensure enough freshwater reaches Texas' bays and estuaries to maintain (or improve) ecological health of these important ecosystems by:

- Conducting studies and analyses to support the revision of environmental flow standards pursuant to the adaptive management process of Senate Bill 3, enacted in 2007, in order to identify flow levels adequate to protect healthy streams, rivers, and bays.

- Establishing set-asides, pursuant to Senate Bill 3, of reasonable amounts of unappropriated water to help maintain critical freshwater inflow.
- Identifying and implementing affirmative strategies for converting some water previously permitted for other uses, including return flows, to freshwater inflow protection as contemplated by Senate Bill 3 to protect freshwater inflows to key habitats.
- Restoring natural hydrological flow by enhancing tidal connectivity where feasible.

### Build resilient coastlines and communities that can withstand projected changes and extreme events by:

- Prioritizing natural infrastructure and nature-based strategies to shore up coastal resources and defend from extreme storm events, particularly in low to moderate income communities, physically vulnerable areas, and areas with critical facilities identified in this assessment.
- Participating in the Texas General Land Office's Technical Advisory Committee dedicated to scoping and conceptualizing coastal projects for the Texas Coastal Resiliency Master Plan.
- Integrating proactive hazard mitigation and resilience planning by incorporating climate change projections in future coastal development and infrastructure expansion.
- Building up community capacity through shared data repositories for hazards and risks specific to the region and through participatory workshops to help develop their coastal restoration projects. (For example, the Community Health and Resource Management (CHARM) workshops hosted by the Texas Community Watershed Partners of Texas A&M University, and The Coastal Restoration Toolkit developed by Restore America's Estuaries).

## Conclusion

This assessment provided scientific evidence that sea level rise, coastal storms, temperature and extreme precipitation are likely to continue increasing by the end of this century. For the Texas Mid-Coast, this will cause significant consequences to the natural assets such as wetlands, whooping cranes, physical assets such as critical infrastructure (hospitals, schools, etc.), socially vulnerable groups, and other socio-economic sectors such as fisheries and ecotourism. The findings further strengthen the importance of drawing attention of decision-makers towards the future impacts of climate change in the region. With a stronger understanding of these vulnerabilities, this assessment synthesized adaptation actions, funding options, and tools for resource managers to enhance coastal resilience during this century. A set of policy recommendations are outlined for incorporating climate change considerations and promoting an effective, efficient, and inclusive future of the Mid-Coast.



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# APPENDIX A: LIST OF DATA SOURCES

| Potential Risk | Data Source | Data Type |
|---|---|---|
| Sea level rise | Sea Level Rise Data, NOAA | Geospatial |
| Storm surge | Texas Coastal Resiliency Master Plan, Texas General Land Office | Geospatial |
| Temperature and precipitation | The Climate Explorer, U.S. Global Change Research Program | Statistic |
| Population | Texas Demographic Center | Statistic |
| Land cover | Texas Coastal Resiliency Master Plan, Texas General Land Office | Geospatial |
| Water quantity and quality | Texas Water Explorer, The Nature Conservancy | Statistic |
| Critical Facilities | National Structures Dataset, USGS | Geospatial |
| Fisheries | Water Quality Point Measurement, Water Data for Texas | Statistic |
| Ecotourism | Outdoor Recreation Satellite Account (ORSA), Outdoor Industry Association Travel Impacts, Travel Texas | Statistic |

# APPENDIX B: GIS METHODOLOGY

The sea level rise data from NOAA was downloaded, and the following steps were performed to conduct the overlap analysis:

- The floating raster was converted to integer type using Spatial Analyst Tools.
- Integer raster was converted to vector polygon using Data Conversion Tools.
- These steps were repeated to create polygons of 3 feet, 5 feet, and 7 feet sea level rise scenarios, and shapefiles were added to ArcGIS Pro.
- The National Structural Dataset for Texas containing point shapefiles of College/University, Fire Station/EMS Station, Law Enforcement, Prison/Correctional Facility, State Capitol, Hospital/Medical Center, Ambulance Services, Cemetery, and Post Office was added to ArcGIS Pro.
- Data was projected to GCS_North_American_1983 Geographic Coordinate System.
- To perform overlay analysis, the Selection by Location Tool was used to identify point shapefiles of critical infrastructure located within the sea level rise polygons.

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