Texas Coastal Bend Regional Climate Change Vulnerability Assessment

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Content

Abstract

The Texas Coastal Bend Regional Climate Change Vulnerability Assessment identified potential changes caused by a changing climate and environment in the Coastal Bend area. It assessed how current changes in climate stability could have future effects on sea level, storms, hydrology, geomorphology, natural habitats and species, land use, economy, human health, infrastructure and cultural resources. The assessment identified the stressors that are adding pressures to the ecosystems and humans in the Coastal Bend area. It also used multiple future scenarios of climate change to identify the impacts and vulnerabilities of the different sectors that represent relevant coastal environments and communities in the study area. To understand the regional needs, stakeholders of the Coastal Bend area provided additional input at a workshop regarding aspects that they considered relevant about their vulnerabilities and opportunities for building resiliency. The study concludes with a series of recommendations for reducing vulnerabilities and promoting natural and community resiliency. It is expected that it will contribute in the identification of action items to be added to the revised Comprehensive Conservation and Management Plan of the Coastal Bend Bays and Estuaries to inform adaptation strategies for the region.

Overview of Drivers & Stressors

Climate Change in the Coastal Bend Region

Although climate is naturally variable, the Texas Coastal Bend is experiencing the impacts of some of the stressors of climate change described here in its coastal and land environments and communities. Multiple physicochemical integrations occur and create the stressors and direct relationships of causation are hard to make due to the complexity of the natural systems.

Drivers

Alteration of atmospheric chemistry

Variability of air & water temperature

Alteration of rainfall patterns

Deforestation & other land use changes

Technological change

The majority of driving forces of climate change are of global scale, however, some local aspects such as land use changes and technological options provide opportunities to reduce negative interactions regionally.

Stressors

Sea level rise

Storm severity & frequency

Rainfall

Drought

Landform changes

Wildfires

Stressors of the natural and human systems occur as a result of changing means, variability and extreme events in temperature and rainfall. These are other pressures impact the structure and processes on which society depends.

Acronyms

4AR	Fourth Assessment Report (IPCC)
AR5	Fifth Assessment Report (IPCC)
BEA	Bureau of Economic Analysis
CBBEP	Coastal Bend Bays & Estuaries Program
CCMP	Comprehensive Conservation Management Plan
CBP	County Business Patterns
CBRWPG	Coastal Bend Regional Water Planning Group
CCIA	Corpus Christi International Airport
CCR	Choke Canyon Reservoir
CDC	Center for Disease Control
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GCA	Gulf Coast Aquifer
GCD	Groundwater Conservation District
GHG	Greenhouse Gas
GVCA	Gulf Coast Vulnerability Assessment
IPCC	Intergovernmental Panel on Climate Change
LCC	Lake Corpus Christi
MANERR	Mission-Aransas National Estuarine Research Reserve
MRP	Mary Rhodes Pipeline
MSL	Mean Sea Level
MW	Megawatts
NCA	National Climate Assessment
NCDC	National Climate Data Center
NOAA	National Oceanic and Atmospheric Administration
ppm	Parts per Million
RCP	Representative Concentration Pathways
RF	Radiative Forcing
SLAMM	Sea Level Affecting Marshes Model
SLOSH	Sea, Lake and Overland Surges from Hurricanes model
SLR	Sea Level Rise
SPMWD	San Patricio Municipal Water District
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
STWA	South Texas Water Authority
TAR	Third Assessment Report (IPCC)
TCEQ	Texas Commission on Environmental Quality
TNC	The Nature Conservancy
TWDB	Texas Water Development Board
U.S.	United States
USGCRP	U.S. Global Change Research Program
WCID	Water Control and Improvement District
WTP	Water Treatment Plan
WWT	Waste Water Treatment

Introduction

Predictions of climate change suggest that sea level rise (SLR), storm intensity and surge, drought, rainfall and hydrology, and acidification will be impacting our coastal zones during this century. With all these possibilities for the future, conserving and maintaining the valuable biodiversity and communities in the Coastal Bend area is more crucial than ever. The failure in designing and implementing effective avoidance, mitigation, minimization and adaptation strategies will result in large costs for addressing the climate change problem to the public and the Coastal Bend Bays & Estuaries Program (CBBEP).

Over the next century, the climate in Texas is expected to experience additional changes. For example, based on projections made by the Intergovernmental Panel on Climate Change (IPCC) and results from the United Kingdom Hadley Centre's climate model (HadCM2), a model that accounts for both greenhouse and aerosols, by 2100 temperatures in Texas could increase by about 1.7 °C in spring and about 2.2 °C in other seasons. Texas emits more carbon dioxide into the atmosphere than any other state in the United States. Additionally, if Texas were a country, it would be the seventh-largest carbon dioxide polluter in the world (U.S. Environmental Protection Agency 2016). Texas's high carbon dioxide output and large energy consumption is primarily a result of large coal-burning power plants and gas-guzzling vehicles (low miles per gallon). A warmer and drier climate would lead to greater evaporation, as much as a 35% decrease in stream flow, and less water for recharging groundwater aquifers (Ward 2011) Climate change could also drop yields in agriculture. In Texas, acres farmed and production of corn and sorghum are expected to decline (McCarl 2011). Climate change projections for the extent and density of forested areas in east Texas vary greatly, stating that they could change little or decline by 50-70%. Hotter, drier weather could increase wildfires and the susceptibility of pine forests to pine bark beetles and other pests, which would reduce forests and expand grasslands and arid scrublands.

The study area of this assessment encompasses six coastal counties of the Texas Coastal Bend. The counties included are, from north to south: Refugio, Aransas, San Patricio, Nueces, Kleberg and Kenedy. The area covered has 1.6 million ha, and it includes five of the major bays of the central Texas coast: Copano, Aransas, Corpus Christi, Upper Laguna Madre and Baffin; and three major population areas: the Aransas Pass-Rockport-Fulton corridor (~6383 ha); the cities around Corpus Christi Bay area that include Corpus Christi, Portland, Ingleside and Port Aransas (~50,000 ha); and Kingsville (~3582 ha). The estuarine areas of the Coastal Bend area are composed of a barrier island system that provide protection to a variety of aquatic habitats, including salt and freshwater marsh wetlands, seagrass beds, oyster reefs and tidal flats. The range of black mangrove in Texas continues to expand along the southern and central coasts, but it rarely constitutes the dominant vegetation, except for the large patches in Harbor Island (across from Port Aransas). The upland environments consist of coastal grassland, dune vegetation, shrub and other woody vegetation, such as live oak forest (around the Rockport Peninsula), and agricultural land. The largest freshwater flow is provided by the Nueces River that meets the estuarine environments at the Nueces River delta and estuary, which are major ecological components of Corpus Christi Bay system. The main industries and employers in this area are comprised of the Port of Corpus Christi, 9 petroleum refineries in Nueces County, the Naval Air Base, the campuses of Texas A&M University-Corpus Christi and Texas A&M University-Kingsville, and a number of manufacturing plants. Coastal tourism constitutes the main services industry of the Coastal Bend area, with recreational fishing, beach activities and bird watching being its main economic components.

The study area for this Climate Change Vulnerability Assessment is within the program area of the CBBEP[1]. The CBBEP was established in 1994 as one of 28 National Estuary Programs. The CBBEP is a non-regulatory, voluntary partnership effort working with industry, environmental groups, bay users, local governments and resource managers to improve the health of Coastal Bend area in Texas. The CBBEP works to implement their Comprehensive Conservation and Management Plan (CCMP; Texas Natural Resource Conservation Commission 1998), which is organized around seven priority issues that will be impacted by a changing climate and environment. The CBBEP is revising its CCMP to align with the Environmental Protection Agency's (EPA) Climate Ready Estuaries Program initiative. This initiative works to help the National Estuary Programs to address climate change in watersheds and coastal areas by coordinating with other federal agencies and external partners that work on coastal adaptation efforts.

The Texas Coastal Bend area is already experiencing the effects of some of these stressors of climate change. Scenarios and findings from the SLR model used by The Nature Conservancy (TNC) in 2013 suggest that sea level rise could increase by at least one meter by the year 2100. Rising marine water poses a variety of threats to coastal communities, including water-related goods and services that are essential to human well-being. Exacerbating this acceleration of climate change, coastal communities are at even greater risk as their natural buffers such as coastal wetlands and dunes are lost. Mangroves, marshes, seagrass, oyster reefs and coral reefs are already under enormous human pressure and their ability to be resilient is now in question. Rising seas, increased storm intensity, warming temperature and acidifying waters will further compromise the ability of coastal ecosystems to provide ongoing critical ecosystem services for communities. Negative changes in freshwater quality also have direct and indirect implication on human and ecological communities that provide other numerous benefits to coastal communities. For example, salt water intrusion can impact drinking water and change habitats; rising sea level can increase water depth which inhibits light from reaching seagrasses and causes major declines in this important local resource.

[1] http://www.cbbep.org

This assessment aims to inform planners, managers, decision makers, scientists and general public on the potential impacts of several climate change stressors and the vulnerabilities of coastal habitats, species, infrastructure, economy and health in the Coastal Bend area in Texas. This project intends to identify essential aspects of the vulnerability in the Coastal Bend area, and some opportunities to enhance adaptation to these stressors. The report synthesizes existing climate change data, models, and future scenarios. Additionally this project has developed key partnerships with local scientists, managers and decision-makers. We hosted a stakeholder's workshop to disseminate preliminary results to the community and gather input on building coastal resilience. We hope that this assessment report will support the CBBEP in reviewing action items within the CCMP to inform adaptation strategies for the region.

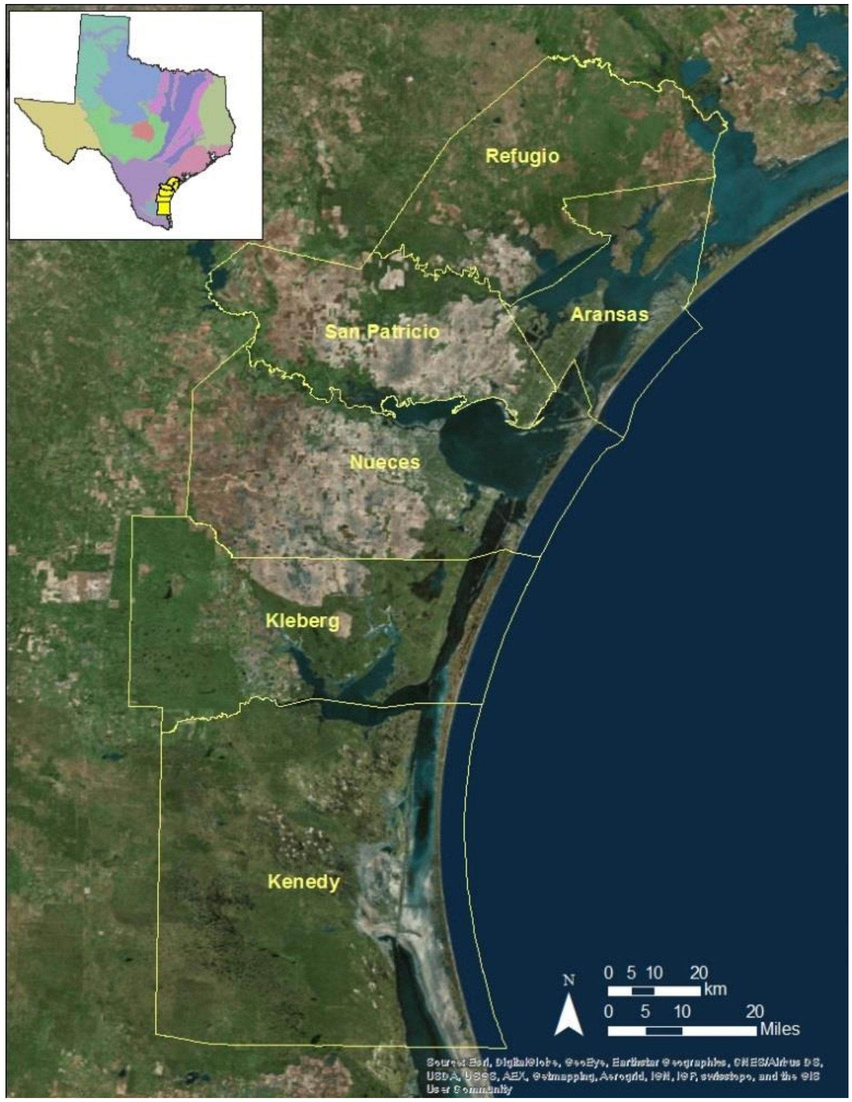

Figure 1.The study area encompasses the coastal counties of the Coastal Bend region in Texas. There are 6 counties in this assessment: Refugio, Aransas, San Patrico, Nueces, Kleberg, and Kenedy counties. Inset shows ecological regions in Texas.

Climate change context—past evidence of climate change

Climate

Climate is naturally variable; over the past millennia the Earth has experienced a medieval warm period (~900 – 1200 A.D.), the Little Ice Age (~ 1500 – 1850 A.D.), and again is warming (Figure 2; Mann et al. 2008).

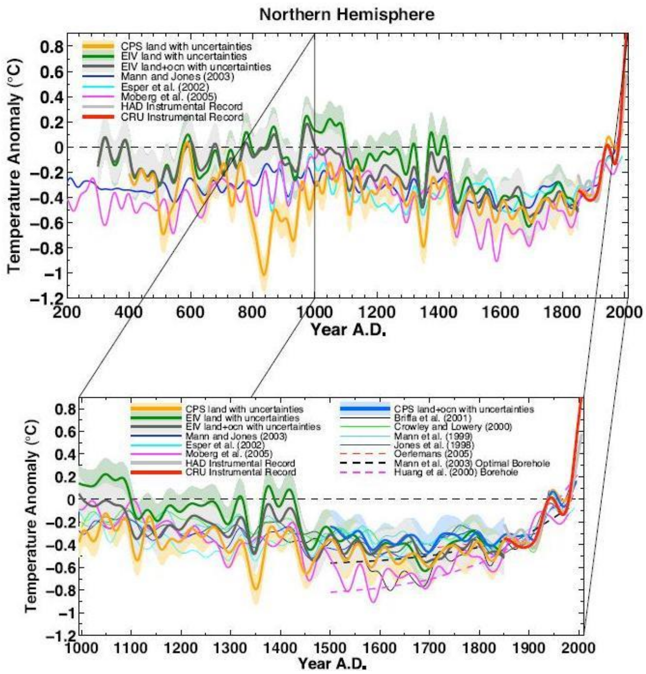

Figure 2. Reconstructed temperature anomalies for the Northern Hemisphere. Inset displays the decrease in temperature associated with the Little Ice Age and the swift increase in temperature since the industrial revolution. Figure source: Mann et al. 2008.

The amount of energy entering and leaving Earth's system influences climate which in turn is driven by solar radiation[2] (Figure 3). Solar radiation is absorbed, reflected, and re-radiated back to space by Earth's surface and atmosphere. Absorbed energy causes the Earth to warm and heat radiated

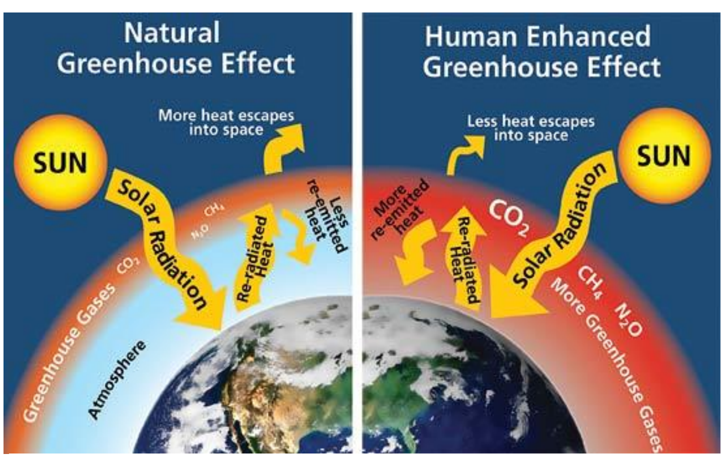

Figure 3. Representation of the natural greenhouse gas effect (left) and how increased emissions of heat trapping gases increases the greenhouse gas effect (right). Figure source: William Elder, National Park Service.

[2] http://www3.epa.gov/climatechange/science/causes.html

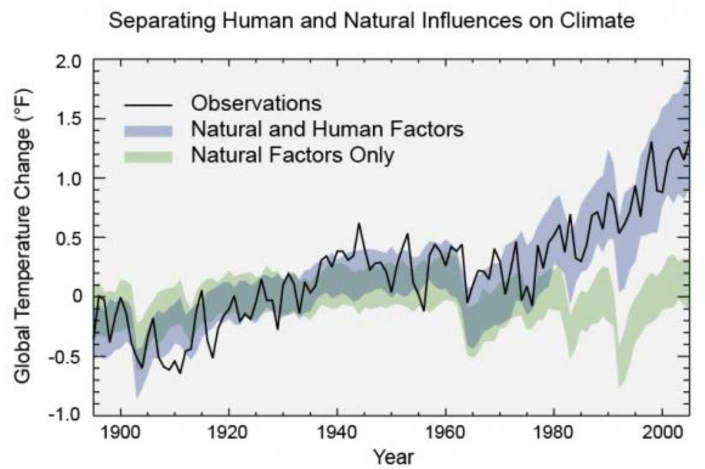

Figure 4. Observed global average temperature changes (black line), with model simulations using only natural factors (solar and volcanic) and model simulations using natural factors plus human produced emissions. Figure source: Walsh et al. 2014.

back out to space from Earth causes Earth to cool. Reflected energy that returns to space before entering Earth's atmosphere does not make a change to Earth's temperature. The existence of Earth's atmosphere and the associated heat-trapping gases found there, known as "greenhouse gases", allows life to exist on Earth. Some of the re-radiated heat is trapped by greenhouse gases, causing the Earth-atmosphere system to retain more heat creating a habitable environment. This is known as the "greenhouse effect". Without the blanket of atmosphere, Earth's temperature would vary drastically between day and night cycles (for example, the moon, which has no atmosphere, varies from 123 °C to -233 °C[3]).

Air Chemistry

Even though climate is inherently variable, natural factors alone cannot account for the recent change in the climate system (Figure 4). For the past half century, an increase in greenhouse gas (GHG) concentrations has enhanced the greenhouse effect allowing more heat to be trapped in the Earth-atmosphere system, likely driving the increase in global temperature presently observed (IPCC 2013a). The EPA announced that carbon dioxide accounted for 82% of all United States (U.S.) GHG emissions in 2013. While carbon dioxide is found naturally in the atmosphere, the concentrations have drastically increased due to human emissions such as fossil fuel combustion, land use change, and chemical reactions. From Figure 5, we see that for the last 800,000 years, carbon dioxide concentrations have fluctuated between 180 to 300 ppm (parts per million). Presently, carbon dioxide is at unprecedented concentrations of 402 ppm (February 2016) at the National Ocean and Atmospheric Administration (NOAA) Mauna Loa Observatory in Hawaii[4].

[3] http://www.nasa.gov/moon

[4] http://www.esrl.noaa.gov/gmd/ccgg/trends/

Temperature

Past trends provide strong support for the direct correlation between carbon dioxide concentrations and temperature variations (Figure 5; National Research Council 2010). Carbon dioxide and other greenhouse gases trap and re-emit heat into Earth's system. With higher concentrations of GHG in the atmosphere, less heat escapes to space causing Earth to warm. This is termed the "Human enhanced" greenhouse gas effect (Figure 3). Since 1895 there has been a 0.72 – 1.06 °C (1.3 – 1.9 °F) increase in U.S. temperatures with a majority of this increase taking place after the 1970s (National Climate Assessment 2014). This rapid increase in temperature has resulted in 2014 being the warmest year on record with 7 of the 10 warmest years in the U.S. occurring since 1998 (U.S. Environmental Protection Agency 2014)

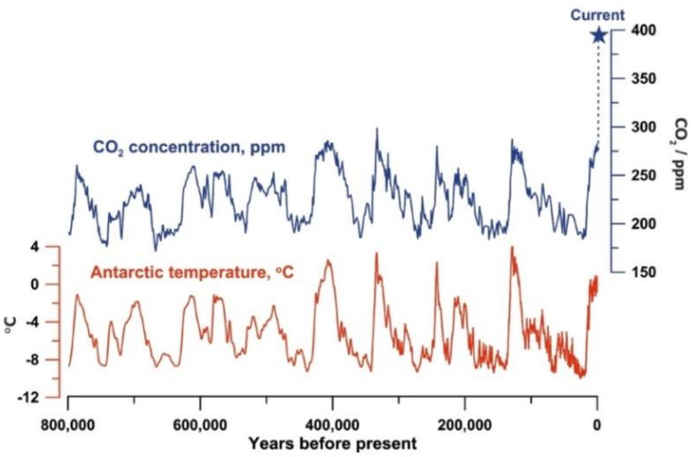

Figure 5. Data from ice cores have been used to reconstruct Antarctic temperatures and atmospheric CO2 concentrations over the past 800,000 years. The current CO2 concentration (blue star) is from atmospheric measurements. Figure source: National Research Council 2010.

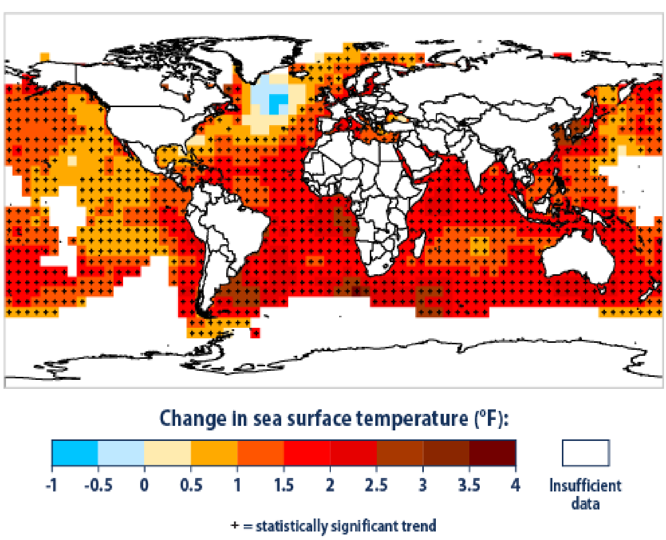

Figure 6. The map depicts the change in sea surface temperatures change between 1901 and 2012. A black "+" symbol in the middle of a square on the map means the trend is statistically significant. Figure source U.S. Environmental Protection Agency 2014.

Global warming is not limited to Earth's atmosphere. In 2014, global ocean temperatures were the warmest on record. Sea surface temperature has increased at a rate of 0.072 °C (0.13 °F) per decade since 1901 (Figure 6). In all Texas bays, winter water temperature has been increasing since 1993 (Tolan et al. 2009). According to the latest assessment report by the IPCC (5th Assessment Report), by the end of the 21st century most of the energy absorbed by the ocean will be constrained to the uppermost 2000 m. Due to the long time-scales of heat transfer, ocean warming will continue even if GHG emissions are decreased (IPCC 2013a).

Water Chemistry

The ocean is also directly affected by carbon dioxide emissions. The ocean absorbs roughly 25% of the CO_2 we emit into the atmosphere, altering the water chemistry (Figure 7). CO_2 causes the seawater to become more acidic as CO_2 readily binds to water molecules producing carbonic acid (H_2CO_3) which then dissociates to bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydrogen (H+) ions. The increase of hydrogen ions to ocean water drives ocean acidification. Seawater pH has dropped by 0.1 in the past 200 years. Since pH is measured on a logarithmic scale, this translates to a 30% increase in acidity[5]. This rate of acidification has not been observed in over 300 million years (Honisch et al. 2012).

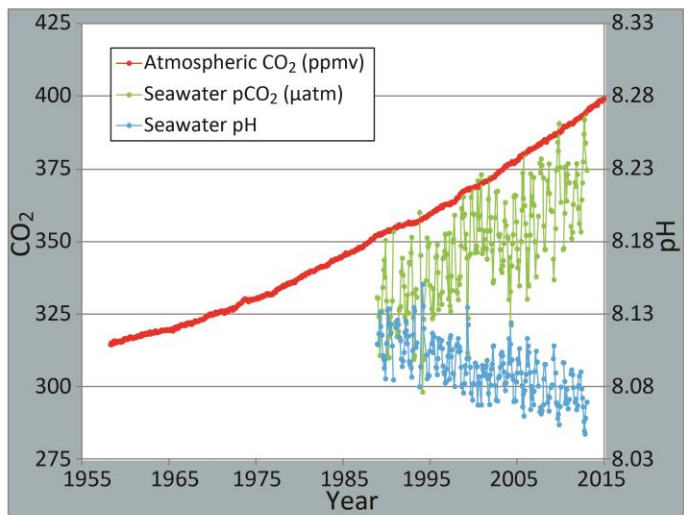

Figure 7. Correlation between atmospheric carbon dioxide concentrations (red), seawater carbon dioxide levels (blue), and the pH of seawater at NOAA observation stations in Hawaii. Figure source: NOAA Pacific Marine Environmental Program: Carbon

In addition to acidification, higher levels of CO_2 in seawater also reduces the saturation state of calcium carbonate minerals (Bryant 2015). Lower saturation states can either leach out these minerals from calcifying organisms or the organisms will have to devote more energy to calcification.

[5] http://www.nrdc.org/oceans/acidification/default.asp

Climate change stressors

Modern day society lives under the assumed presence of a stable climate. Homes are built on the premise that they are outside a flood zone, crops are sowed with the expectation that rain will fall, and economies take for granted every "good season". However the security of a stable climate is being tested as we have seen from recent stressors such as SLR, precipitation change, and increased storm severity (IPCC 2013a). The following discussion will introduce stressors that may impact the structure on which society depends.

Sea Level Rise

As water temperatures increase, so does sea level as water molecules expand as they are warmed. This phenomenon is known as *thermal expansion*. But thermal expansion is only one factor contributing to SLR due to climate change. As surface temperatures increase, polar ice sheets and glaciers melt, adding additional water to the ocean. With rising sea levels, low lying areas will become permanently inundated, changing the landscape and displacing societal development in coastal areas.

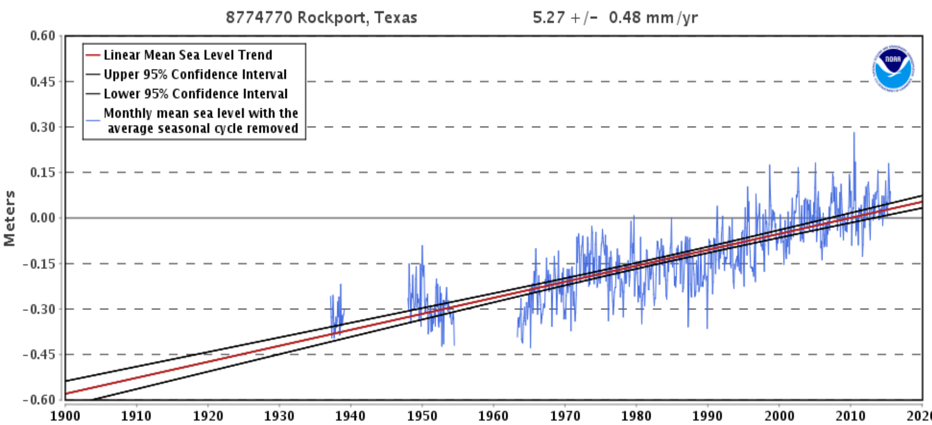

Figure 8. Mean sea level trend from 1937 to 2014 at NOAA Station 8774770 in Rockport, Texas. Figure source: NOAA Tides & Currents.

Global mean sea level has been rising at a rate of 1.7 mm per year since 1900 (Church and White 2011), but local trends of the Texas coast suggest a higher rate of 2 – 7 mm per year or about 1-2 inches per decade[6] (Figure 8). The rate at which SLR occurs will determine the ability of coastal ecosystems and communities to adapt to the change. Coastal habitats such as salt marshes may be able to migrate landward as SLR occurs. However, coastal habitats that are backed by development or inhospitable habitat are at risk of being lost. Additionally, the rate of mean SLR is projected to increase compared to the current rate, resulting in a mean sea level up to 2 m above 1992 levels by 2100 (Parris et al. 2012), which will only exacerbate the aforementioned issues.

Storm Severity & Frequency

Large uncertainties exist when trying to model the relationship between storm severity and frequency and global warming. Global climate models that project weather patterns such as precipitation and air temperature are not able to project such localized events. Some studies suggest that thunderstorms are likely to increase due to increased surface temperatures which result in the increased ability of the atmosphere to hold water, as well as, increasing evaporation rates (Trapp et al. 2007; Diffenbaugh et al. 2013). The past decade has resulted in significantly higher numbers of extreme storm events (thunderstorms, winter storms, hurricanes), but it is unclear if this trend will continue as temperatures increase (Walsh et al. 2014).

Since the 1970s, there has been an increasing trend in tropical storm severity and power dissipation index, a measure that combines intensity, lifetime and frequency of storms in a season (Biasutti et al. 2011; Geophysical Fluid Dynamics Laboratory 2015). The occurrence rate of Atlantic hurricanes has slightly increased in the past 3 decades with 0.13 hurricanes/year (Figure 9). Projecting this rate to 2100 suggests an additional 11 hurricanes occurring per season over the baseline in 2012[7]. Despite the fact that storm intensity and frequency has increased in recent decades, it is inconclusive if the change is natural or human-induced. The existing knowledge that hurricanes are

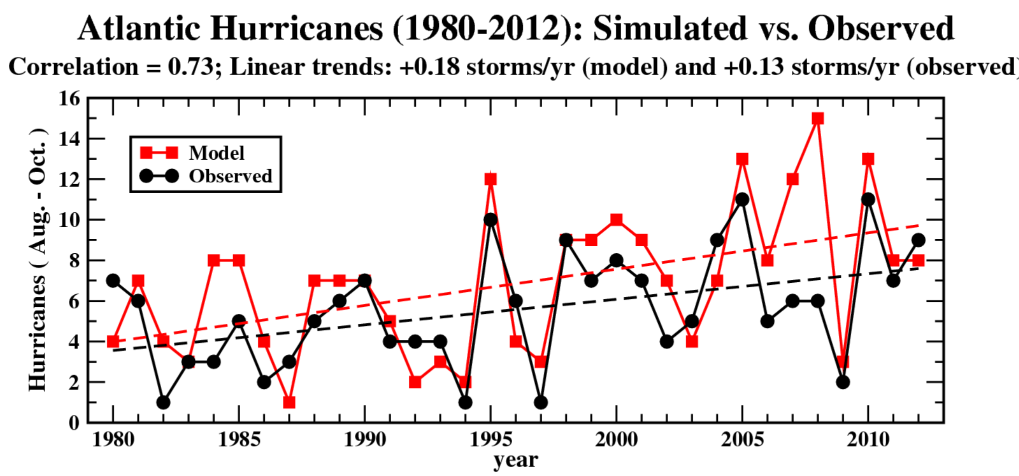

Figure 9. Simulated vs. observed Atlantic hurricane counts (Aug.-Oct) for 1980-2012. Figure source: Geophysical Fluid Dynamics Laboratory 2015.

[6] http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml

[7] http://www.gfdl.noaa.gov/global-warming-and-hurricanes

only likely to form in areas of relatively high sea surface temperature (SST; Gray 1979), has created the causal relationship between increasing SST by global warming and increasing hurricane formation. While the relationship is not scientifically proven, it should draw some concern.

Rainfall

Rainfall is naturally variable across the U.S. There is a relationship between SST and precipitation where an increase in SST is likely to lead to an increase in precipitation (Biasutti et al. 2011). Based on high emission scenarios; northern latitudes of the U.S. will see an increase in annual rainfall while southern states are likely to see a decrease in annual rainfall (Walsh et al. 2014). However, since 1991, the southern great plains (Texas, Oklahoma, and Kansas) have seen an increase in precipitation (8%; Shafer et al. 2014). As air temperatures increase, the amount of moisture the atmosphere can hold also increases. This means that there is more water available to come down as precipitation. The general consensus is that there will be an increase in heavy precipitation events and a reduction in moderate and low precipitation (Allan and Soden 2008), increasing the likelihood of damaging floods.

Drought

Extreme rainfall events will become more frequent, but the dry days between those events will potentially increase leading to longer dry seasons (Figure 10). Longer dry seasons will put more pressure on groundwater sources, further depleting Texas aquifers. Additionally, less water will flow into coastal bays and estuaries, increasing salinity and decreasing sediment deposits that replenish marshes and barrier islands.

Saltwater Intrusion

Decreased freshwater flow to coastal areas will promote saltwater intrusion. Normally, saltwater does not enter coastal aquifers at unsafe quantities as the supply of freshwater maintains a gradient. As freshwater sources are diverted from aquifers (aquifer cannot recharge due to reduced precipitation, or groundwater is pumped from aquifers) the water table balance is shifted, allowing more saltwater to enter coastal areas causing aquifers to become brackish (U.S. Geological Survey 2013). SLR and increased storm surge could also lead to surface water supplies (i.e. lakes, rivers, reservoirs) to become more saline.

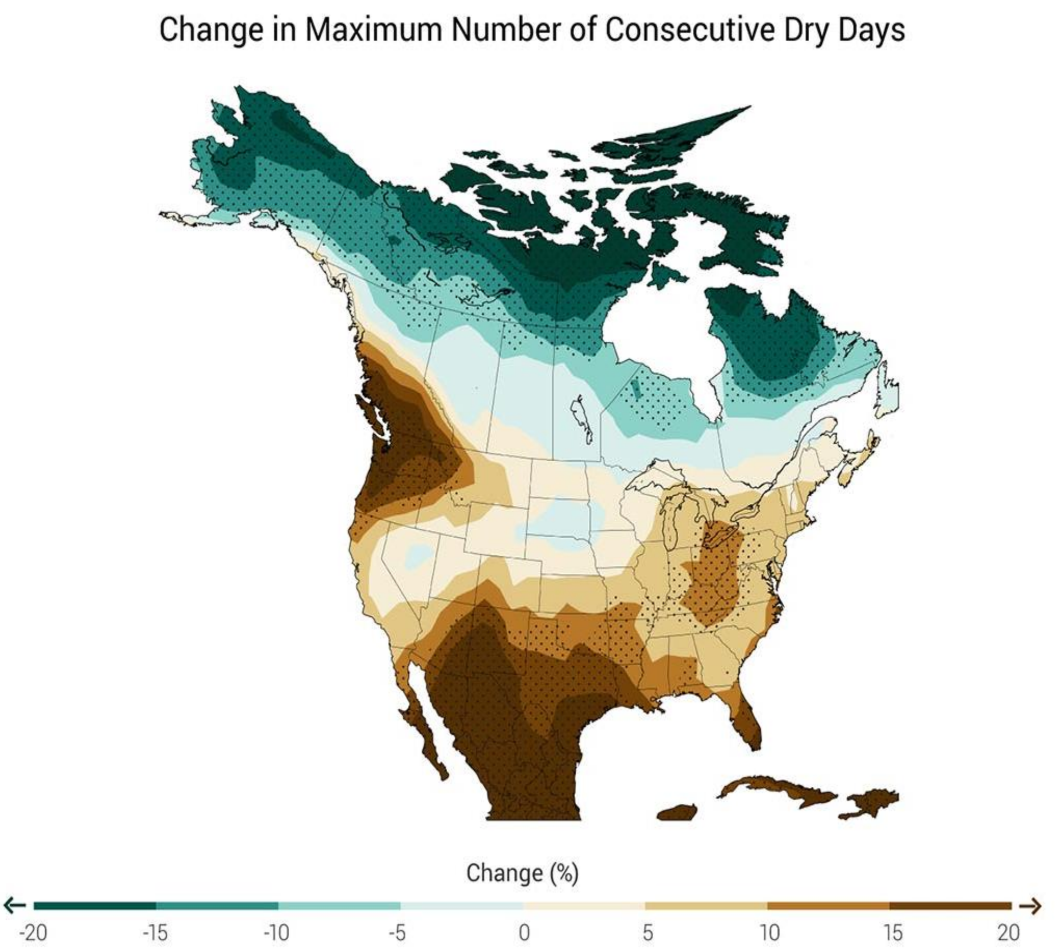

Figure 10. The map depicts change in the number of consecutive dry days (days receiving less than 0.04 inches of precipitation) at the end of this century (2070-2099) relative to the end of last century (1971-2000) under the highest scenario considered in this report, RCP 8.5. Stippling indicates areas where changes are consistent among at least 80% of the 25 models used in this analysis. Figure source: National Climate Assessment 2014 (Walsh et al. 2014).

Landform Changes

Coastal shorelines are dynamic systems that are influenced by SLR, storm frequency and severity, subsidence, and sediment transport. Texas is fringed by a system of barrier islands that protect the mainland from wave action and storm energy. Barrier islands also provide critical habitat for a number of species, and are integral for coastal economies. Most barrier islands are either important tourist attractions or critical nature reserves. Sea level rise and storm severity threaten barrier islands by compromising the protective dune system that lies on the seaward side, causing the island (sediments) to migrate landward. So, not only does climate change impose serious threats to the fragile island communities, but also to the mainland as it loses the first line of defense against storms and erosional forces. Texas shores are already retreating at an average of 0.7 m (2.3 ft) per year due to erosion (Texas General Land Office 2015). Furthermore, this shoreline retreat is occurring along 80% of Texas coastline (Paine et al. 2014).

Wildfires

Climate change is projected to increase the dry season, leading to more severe droughts. In 2011, Texas experienced its driest year on record fueling catastrophic wildfires across the state. By fall 2011, over 1,214,000 ha (3 million acres) had burned due to wildfire[8]. As mentioned earlier, as air temperature increases so does the atmosphere's ability to hold moisture. Likewise, as air temperature increases, so does the rate of evaporation, heightening dry conditions. With drought conditions and air temperature likely to continue to increase, there are increased potentials of wildfires. Wildfires also indirectly impact human health by increasing particulate matter in the air, exacerbating respiratory health conditions (Melillo et al. 2014).

[8] http://www.texasmonthly.com/articles/trial-by-fire/

Climate change scenarios

There is always uncertainty when predicting future events. Forecasts for temperatures, precipitation, storms, and even the winner of a football game can prove to be incorrect. This is also true when trying to predict the future of global climate and the impacts of a changing world. Due to this uncertainty, groups of scientists, like the IPCC and the U.S. Global Change Research Program (USGCRP), have collectively reviewed existing literature on climate change and formed scenarios that project future climate based on differing levels of action taken by humans.

Overtime, IPCC has utilized three sets of scenarios. In 1992 the first generation of scenarios was developed, called IS92. In 2000 the IPCC published the second generation of scenarios referred to as Special Report on Emission Scenarios (SRES). SRES was used in the 3rd and 4th Assessment Report (TAR and 4AR, respectively), and thus much climate change research has been based on these scenarios. This scenario family projects GHG emissions based on narrative storylines that include the demographic, social, economic, technological, and environmental developments. SRES development consisted of first determining socioeconomic scenarios, then climate projections were then able to be formulated. This process is linear in development, meaning research was passed from one research community to the next (social scientists to climate modelers) resulting in a slow, lengthy process.

To address the efficiency issues of SRES, the IPCC recently adopted a new set of scenarios used in the 5th Assessment Report (AR5), called the Representative Concentration Pathways (RCP; IPCC 2013a). In contrast to SRES, RCP scenario development utilized a "parallel" process in which radiative forcing (the driver of global warming) was first developed, allowing for climate scenarios and socioeconomic scenarios to be developed concurrently (Figure 11; Moss et al. 2010).

There are 4 RCP scenarios: RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5, ranging from low to high radiative forcing. Radiative forcing (RF) is the change of energy in the Earth's atmosphere measured in watts per square meter. In terms of GHG emissions, a low RF value would result from low emissions. RCPs range from severely reduced emissions resulting from mitigation (RCP2.6) to "business as usual" where emission rates continue to increase (RCP8.5). The RCP scenarios project that global warming will continue, with a 1.67 – 2.78 °C (3-5 °F) increase for lower emission scenarios and 2.78 – 5.56 °C (5 – 10 °F) for higher emission scenarios (IPCC 2013a). It is likely that even if all greenhouse gas emissions were somehow stopped today, or decrease as in the U.S. between 2007 – 2013 by 11% (Feng et al. 2015), global warming would still occur due to past emissions (Solomon et al. 2008).

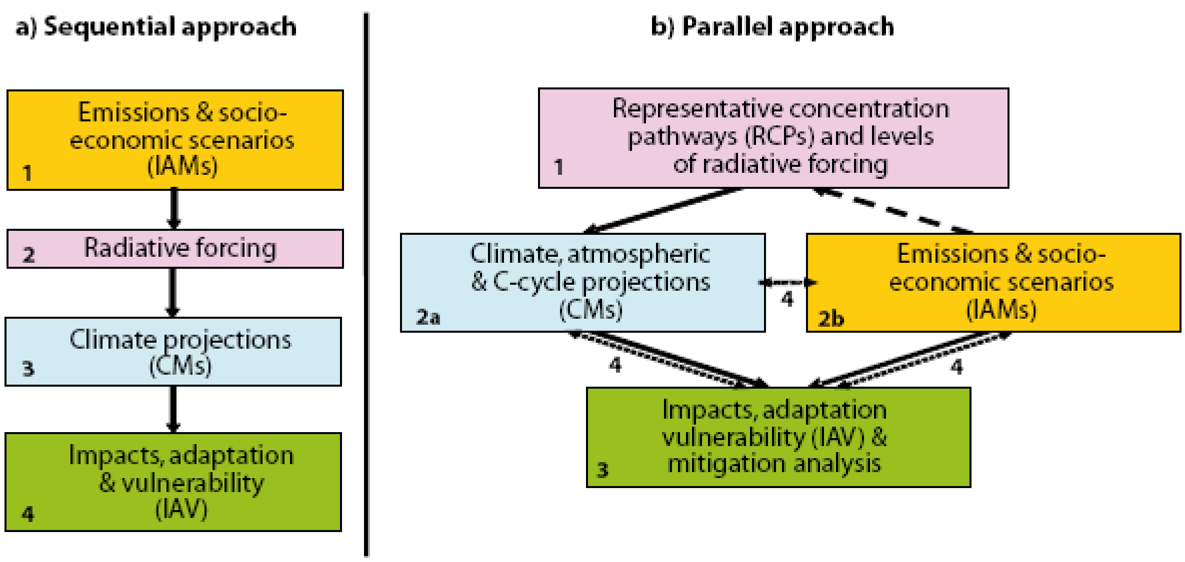

Figure 11. Approaches to the development of scenarios in relation to climate change. a) linear or sequential approach (SRES) and b) parallel approach (RCP). Figure source: Wayne 2013.

This assessment used three scenarios to illustrate the range of potential impacts of climate change. Since SRES has been around longer, more literature exists using these scenarios as a guideline for developing potential impacts of climate change. For instance, the Parris et al. (2012) report developed global SLR scenarios and is in reference to SRES scenarios, as well as, the Third National Climate Assessment (NCA; Melillo et al. 2014) that USGCRP produces. However, to safeguard the assessment from being obsolete over time, RCP scenarios were used by relating the two scenario families. In order to combine the scenario families, literature was reviewed and analogous scenarios between the two families were created based on similar temperature anomalies by 2100 (Table 1).

Table 1. Scenario families related based on the median temperature anomalies by 2100 (adapted from Rogelj et al. 2012).

		Scenarios		
		Low	Mid	High
Scenario Family	RCP (IPCC 2013a)	4.5	6.0	8.5
	Example literature	Rogelj et al. 2012	Rogelj et al. 2012	Watson et al. 2015
	SRES (IPCC 2000)	B1	B2	A2
Temperature anomaly by 2100 since pre-industrial °C °C (°F)		2.5 (4.5)	3.0 (5.4)	5.0 (9.0)
Population growth		Peaks mid-century then declines	Continuously growing	Continuously growing at higher rate than B2
CO_2 concentration (ppm)[1]		~550	~625	>850

IPCC formulates global estimates of SLR but does not account for the potential impacts of future sea ice melt (IPCC 2007). The exact manner in which arctic sea ice melts and its impact on SLR are widely debated topics. Because of this, IPCC SLR scenarios may grossly underestimate the potential future risks from SLR. U.S. studies, including the Gulf Coast Vulnerability Assessment (GVCA; Watson et al. 2015), use the SLR scenarios developed by Parris et al. (2012), as it does include impacts of future sea ice melt. In order to be directly comparable to studies in the same geographic region, such as Parris et al. (2012; U.S.) or GCVA (2015; Gulf coast of U.S.), the assessment used 0.5m, 1.2m, and 2m SLR by 2100.

Three scenarios were chosen because they characterize increasing levels of risk associated with climate change and adequately prepare a community for potential future impacts. RCP 2.6 was not chosen because it illustrates the option of net negative carbon dioxide emissions by the end of the century and does not have an equivalent SRES scenario. It reflects a small climate shift, mainly driven by the level of emissions that has already transpired. This scenario, while possible, does not illustrate the potential negative impacts of a changing climate. RCP4.5, RCP6.0, and RCP8.5 illustrate incremental change that may take place due to increasing levels of carbon emissions. Table 1 shows the associated environmental changes associated with each scenario.

Local Trends and Forecasts for Climate Drivers and Stressors

Average Air Temperature

Air temperature has been continuously monitored in the Coastal Bend area at the Corpus Christi International Airport (CCIA) by NOAA since 1948. Monthly summaries of climatic data were obtained from the National Climatic Data Center (NCDC) and aggregated to get mean annual air temperature for the region (Figure 12)[9].

Since 1948 air temperature has had an increasing trend of 0.006 °C (0.01 °F) per year with an average of 22.78 °C (72.1 °F) annually (1948-2014). However, when focused on only the

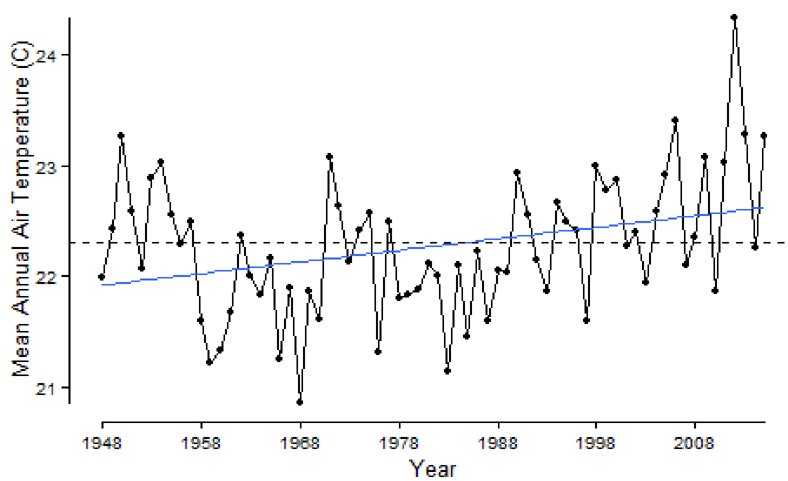

Figure 12. Annual mean air temperatures derived from monthly average at Corpus Christi International Airport (CCIA). The average air temperature from 1948-2014 (dashed line) is 22.78 °C (72.1 °F). An increasing annual trend in temperature (n=65) is observed (blue line; p<0.05). Data obtained from National Climatic Data Center

[9] http://www.ncdc.noaa.gov/data-access

past 30 years (1984-2014), the trend increases 600% to 0.03 °C (0.06 °F) per year. If the trend persists, a one degree increase in temperature will occur approximately every 33 years.

An annual increase in air temperature of 0.03 °C from 2014 would lead to an increase of 2.58 °C (5.16 °F) by 2100. IPCC projects that air temperature increases will range from 2.5 °C to 5.0 °C by 2100 from *preindustrial levels*. Global temperatures have already increased by 0.72 – 1.06 °C since preindustrial levels, suggesting that the rate of increasing air temperature will be unprecedented. Since a warming of at least 0.72 °C has already been detected, the Coastal Bend area is on target for future air temperatures correlating to the intermediate scenario (approximately a 3 °C increase). Moreover, Biasutti et al. (2012) projects that by the end of the century (2075-2099), the coolest summers will be as hot as or hotter than any summer experienced in the last century.

Days per Year Over 90 Degrees

The number of days over 32.2 °C (90 °F) per year has steadily increased over the past century with less than 10 days per year in the 1890's to 127 days in 2014 (Figure 13). To prevent data artifacts produced by different observer groups prior to 1948, the number of days over 90°F was analyzed from 1948 to the most current full year, 2014 (when NOAA started monitoring at CCIA). From 1948 to 2014, the number of days over 32.2 °C increased by 2 days every 5 years. At this rate, which is likely to be a low estimate of rate of increase in air temperatures, 34 more days over 32.2 °C will occur per year by 2100. Comparing mid-century decade averages (1948-1958) to the most recent decade available (2004-2014), there is an approximate increase of 25 hot days.

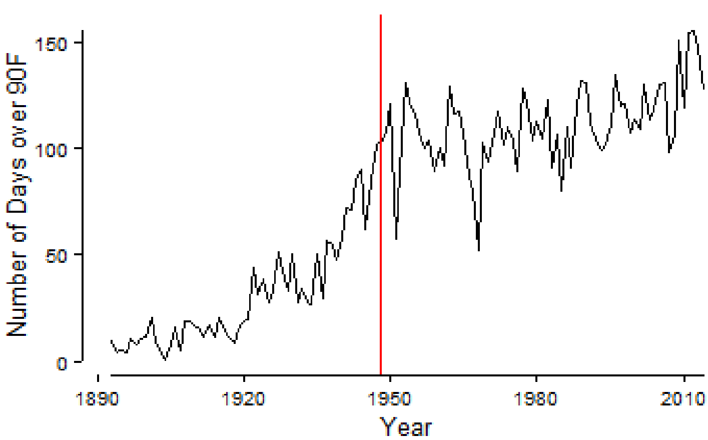

Figure 13. Historical number of days over 90°F (32.2°C) at Corpus Christi International Airport (CCIA) from 1893 through 2014. Red line indicates 1948, the year that NOAA National Climatic Data Center (NCDC) started collecting data at CCIA. Annual data was collected from COOP and obtained from National Climatic Data Center (NCDC 2015).

The American Climate Prospectus[10] (ACP) projects that by the end of the century, under an intermediate scenario (RCP 6.0), there will be over 100 days per year that are 95 °F (35 °C) or hotter in Texas (a ~150% increase). Since this projection is for the entire state, we can assume that the hotter regions of the state will see even more extreme heat days. For reference, there currently around 42 days per year that are over 35 °C (1981-2010).

[10] http://climateprospectus.org/

Coastal Water Temperature

Summer water temperatures were gathered from water quality station data housed by The Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University - Corpus Christi[11]. The stations chosen were in open estuarine water to decrease the influence of temperature due to land-based inputs (Figure 14). Over the past 8 years there has not been a significant change in summer water temperatures in the CBBEP area.

Since the dataset from the water quality stations is less than a decade in length, literature was reviewed to assess long-term trends in water temperature. Lluch-Cote et al. (2013) analyzed SST datasets from NOAA's NCDC in waters surrounding Mexico from 1910 to 2011. They found that the western Gulf of Mexico has been warming for more than 3 decades (Figure 15). SST is likely to continue increasing in the Gulf of Mexico due to increasing surface air temperatures. The high scenario projects up to a 2.0 °C increase in the top 100 meters of ocean water by 2100 (IPCC 2013a).

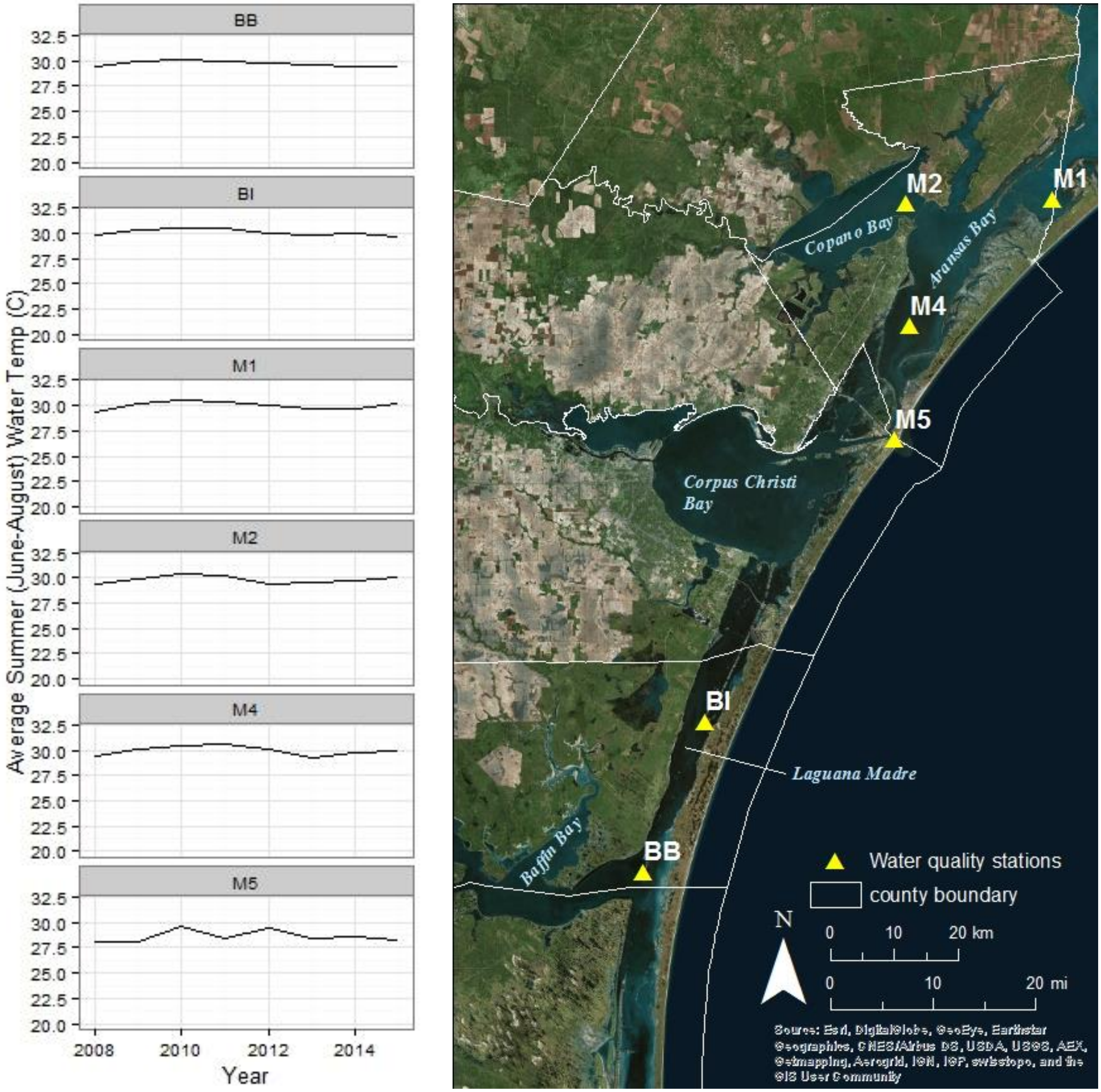

Figure 14. Average summer water temperatures (June, July, August) from 2008 to 2015 at water quality monitoring stations in CBBEP area. Station ID's are: BB=NPS Baffin Bay, BI= NPS Bird Island, M1= MANERR 1, M2=MANERR 2, M4=MANERR 4, M5=MANERR 5. Data was obtained from Texas A&M Corpus Christi Conrad Blucher Institute.

pH

[11] http://www.cbi.tamucc.edu/

Long-term acidification of the coastal bend estuaries has been

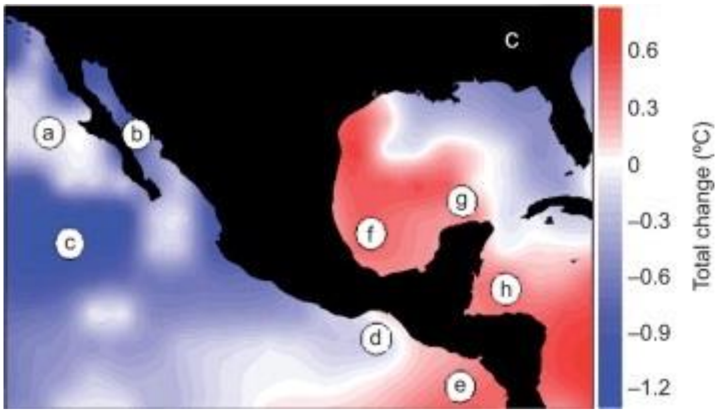

Figure 15. Long-term analysis of SST in waters surrounding Mexico. Western Gulf of Mexico (f) has been warming for more than 3 decades. Figure source: Lluch-Cota et al. 2013.

observed since the 1960's (Hu et al. 2015; Figure 16). Hu et al. (2015) investigated estuarine carbonate chemistry by utilizing a long-term dataset provided by Texas Commission on Environmental Quality (TCEQ). They found that most of the bays in the CBBEP area are suffering from long-term acidification and decreasing alkalinity. With both water parameters decreasing, it will become increasingly more

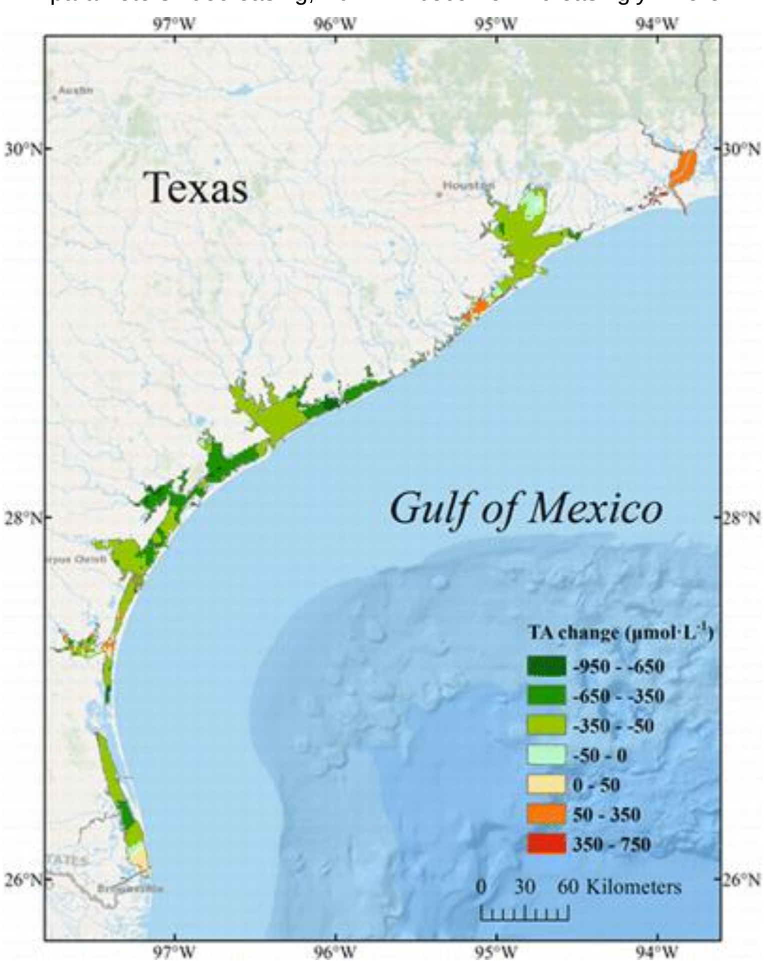

Figure 16. Total alkalinity change in Texas Bays from 1960s to 2010. The greener colors show a decrease in alkalinity which corresponds to a decrease in a water body's ability to neutralize acid. Figure source: Hu et al 2015

energy intensive for calcifying marine organisms (shellfish, corals, plankton, echinoderms) to maintain their skeletons. If acidification continues, these organisms may start to dissolve.

Ocean chemistry changes as more CO_2 is emitted in the atmosphere. The ocean absorbs atmospheric CO_2 causing the pH to decrease and carbonate concentrations to decrease. By 2100, global-mean surface pH may decrease by 0.145 to 0.31 for low to high emission scenarios, respectively (IPCC 2013a). Currently global pH is around 8.1 so a decrease of 0.31 (pH $\cong$ 7.8) corresponds to a 100% increase in acidity.

Rainfall

Rainfall in the central Texas coast has been highly variable with the highest amount of rainfall occurring in 1991 (35.7 cm) and the lowest in 1917 (13.6 cm). Recently, 2011 has had the lowest total annual precipitation of 30 cm (Figure 17) which coincides with one of Texas' worst drought year since recordkeeping began in 1895 (Combs 2012). Areas of the CBBEP have been in "abnormally dry" to "drought" conditions over the past year[12], which will only worsen due to climate change.

Due to high variability, there is not a perceptible trend in precipitation in the area. For instance, when comparing the last century with the past half century, opposite linear trends are observed (Figure 17).

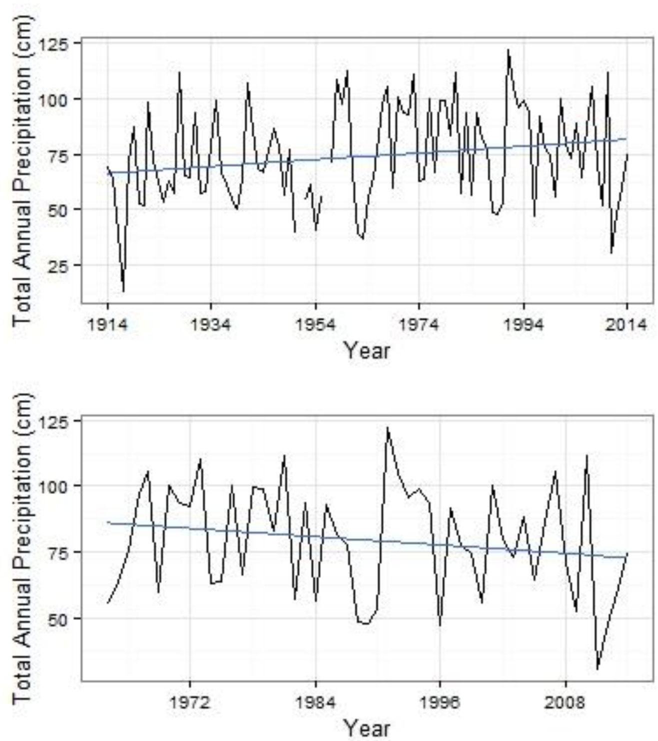

Figure 17. Total annual precipitation at Corpus Christi International Airport. 100 year trend (top) compared to 50 year trend (bottom). Data source: NOAA National Climatic Data Center

12 http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?TX

Both IPCC AR4 & AR5 scenarios project relatively little change in precipitation for the Coastal Bend area. Most dramatic changes will be seen in the Northern latitudes with increased precipitation. The Coastal Bend area may see a 10% decline in precipitation by 2100 based on a low emissions scenario (Figure 18, IPCC 2013b) but could see up to 20% decrease in all seasons except Fall under a higher emissions scenario (Shafer et al. 2014).

Total precipitation may change very little, but the change in delivery may be more important. By 2100, the number of consecutive dry days is projected to increase by 2 (lower emission scenario) to 3 (higher emission scenario) days (Shafer et al. 2014).

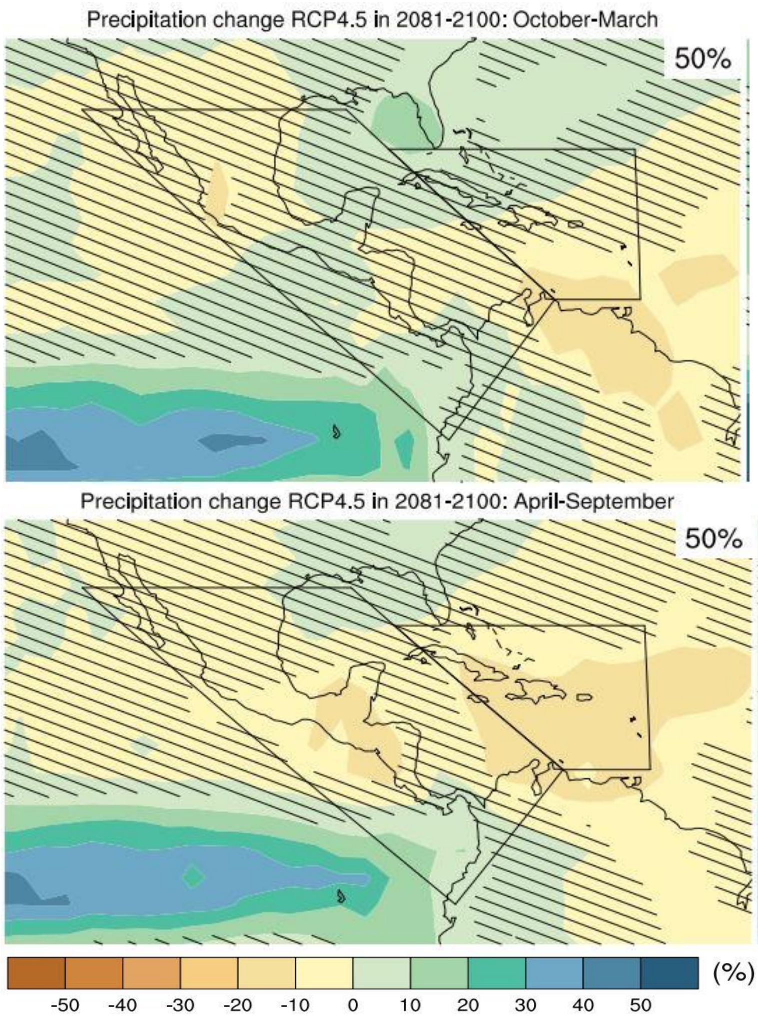

Figure 18. Average model projection of precipitation changes in Central America from IPCC AR5. The Coastal Bend area is projected to see a 10% decrease in precipitation by 2100 compared to average of 1986-2005. Hatching represents areas of high confidence. Figure source: IPCC 2013b.

Sea Level Rise

Since 1900, global mean sea level (MSL) has been increasing at a rate of 1.7 mm/yr (Church and White 2011). However, local estimates for the Coastal Bend region suggest a higher rate of 3 - 6 mm/yr[13]. In Rockport (Aransas County), MSL has been rising at 5.27 mm/yr (Figure 8). In order to properly prepare for SLR at a local level, regional trends should be included to properly assess risk. The scenarios follow the methods used to project SLR provided in Parris et al. 2012. The projections are in reference to MSL derived from the current National Tidal Datum Epoch which is an average of hourly tidal heights over a 19 year period (1986-2001). The mid-point of this time period is 1992 and so it is the reference year NOAA used to project SLR. The low SLR scenario is a linear extrapolation of the current MSL rate for the Coastal Bend area (3.5 mm/yr Corpus Christi; 5.27 mm/yr Rockport), 4.385 mm/yr. Under the low scenario, MSL will increase by 0.5 m relative to 1992. The intermediate scenario takes into consideration the impacts of ocean warming which increases sea level by thermal expansion of water molecules. The intermediate scenario yields a 1.2 m increase in MSL by 2100. The highest scenario represents the possible acceleration of SLR caused by ocean warming and ice sheet loss, resulting in a 2 m SLR by 2100 (Figure 19).

Sea-level rise was obtained from the Sea Level Affecting Marshes Model (SLAMM) which computes relative sea level change based on user input and the impacts of SLR on coastal wetlands. The model incorporates aspects that may influence SLR inundation extent such as erosion/accretion, subsidence, and barriers that may protect areas against SLR. Since this model incorporates these dynamic characteristics of coastal lands, it was chosen over a more general “bathtub” approach which equates SLR extent to the elevation contour on land (i.e. 2 m SLR would inundate to the 2 m elevation contour). The SLAMM outputs were obtained from the Gulf-wide SLAMM project completed by Warren Pinnacle Consulting (Warren Pinnacle Consulting 2015).

[13] http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml

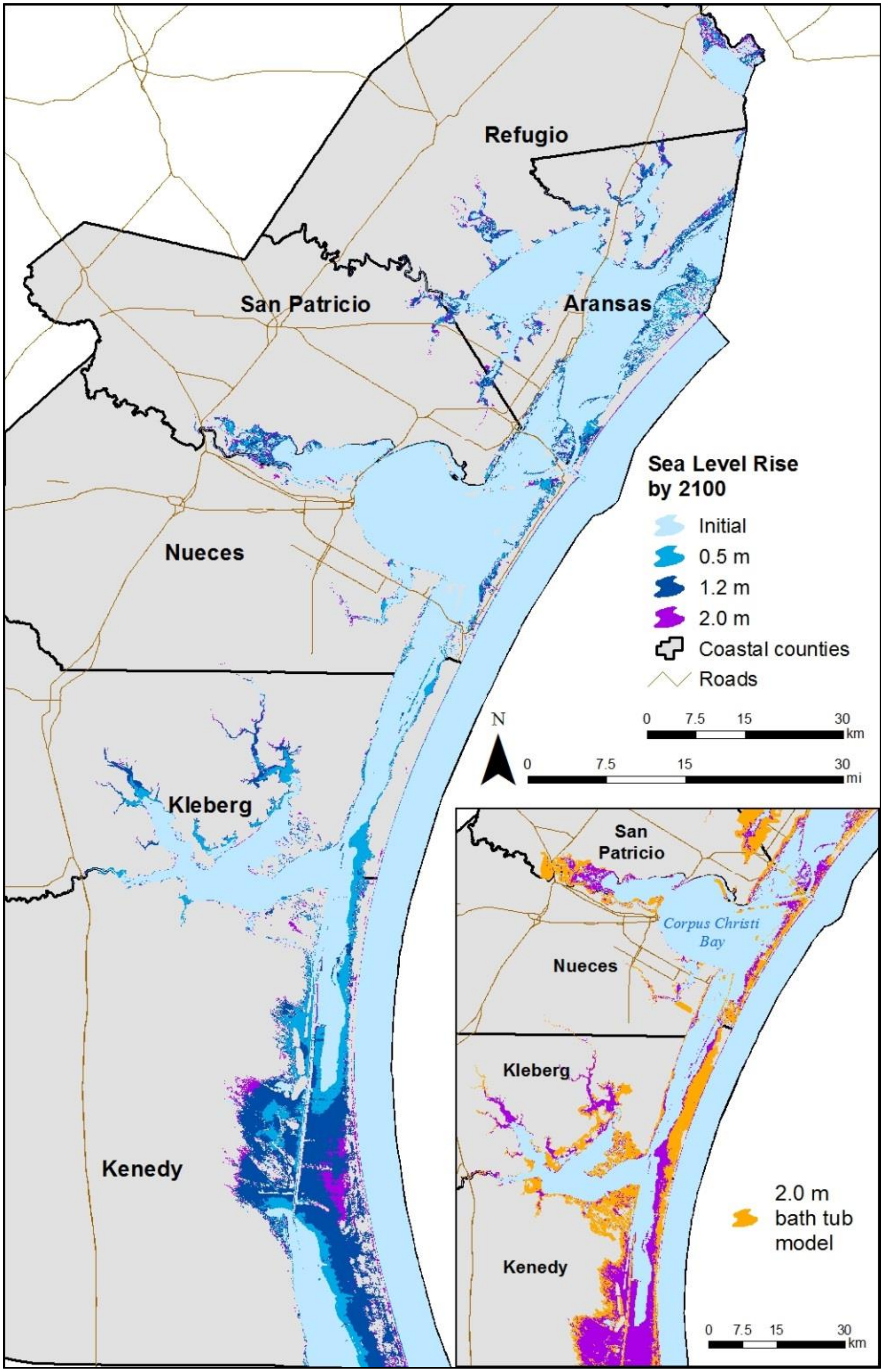

Figure 19. Sea level rise scenarios with initial (light blue), low emission scenario (medium blue), intermediate emission scenario (dark blue), and high emission scenario (purple) depicted by 2100 using SLAMM model predictions. Inset (bottom right) shows SLR estimates of 2 m using a “bath tub” approach. This approach converts land elevation of 2 m or less to water (orange), not accounting for barriers or flow dynamics. Figure source: Warren Pinnacle Consulting 2015; inset source: Weiss et al. 2011.

Climate change impacts by sector

Climate change impacts that are easily identifiable are stressors and sectors that have spatial characteristics. For instance, SLR scenarios can be displayed on a map and users can identify areas of interest impacted by SLR. Similarly, storm surge can also be mapped to show potential areas of inundation based on the category of storm. Providing these "layers" to communities will be useful when more specific impacts need to be assessed. These different spatial visualizations can be layered with sectors to derive direct impacts based on location. Indirect impacts of climate change are harder to visualize but will be discussed in the following sections.

Critical facilities

Critical facilities are those at which society depends and would be crippled without. These include emergency services such as fire stations and hospitals, energy production and supply facilities, trash or solid waste management, facilities that provide safe drinking water, and transportation systems.

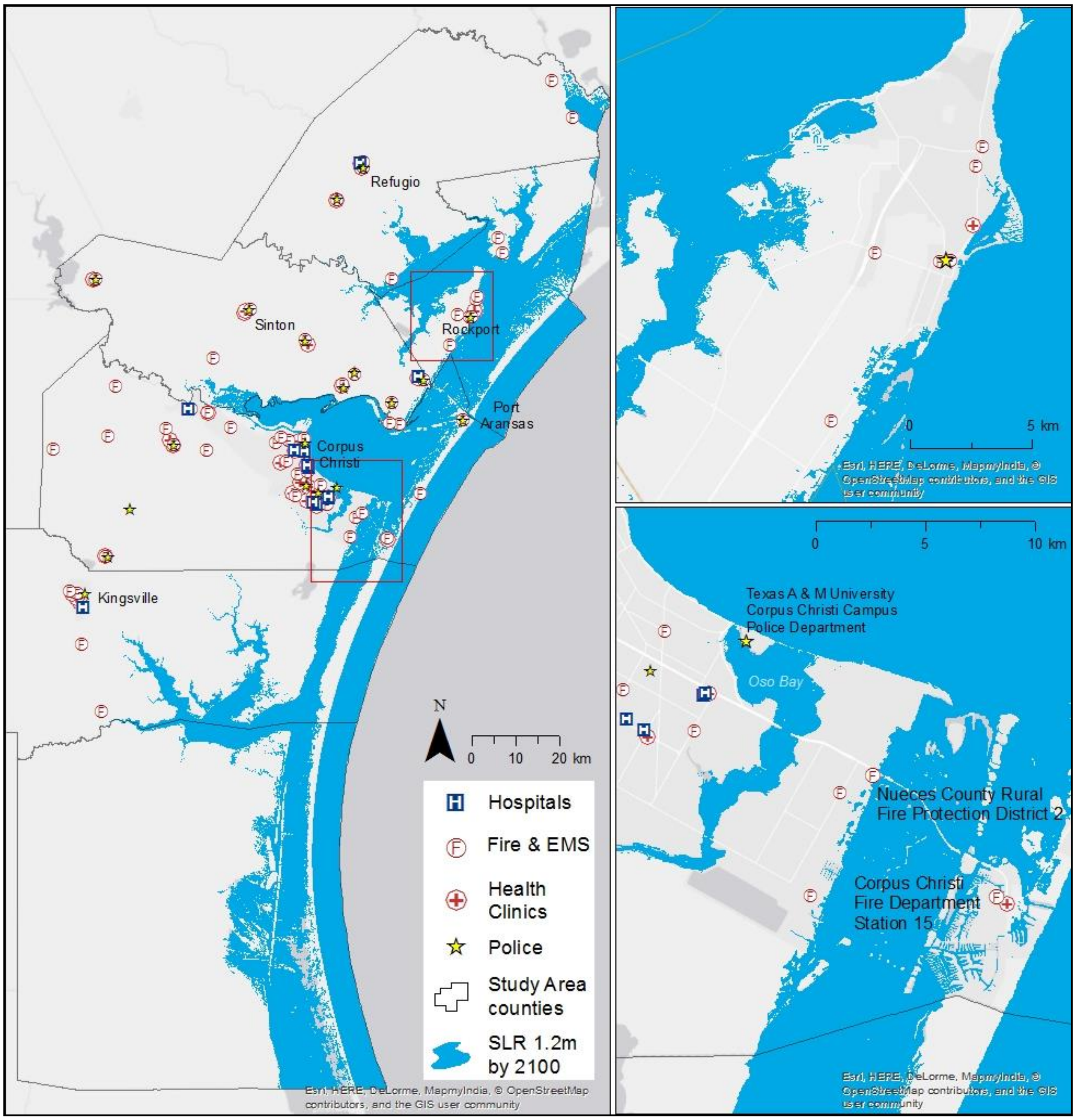

Figure 20. Emergency services such as fire stations, emergency medical services (EMS), and health facilities in 6 coastal counties in Texas. Insets (right) show facilities that are within 150 m of a 1.2m SLR scenario. Data obtained from USGS structures dataset (http://nationalmap.gov/structures.html) and the Texas Gazetteer (https://tnris.org/data-catalog/entry/texas-gazetteer/).

Emergency Services

Fire

In the study area, 59 fire stations and emergency services (including volunteer fire departments) were identified. All stations lie above the highest SLR scenario (2.0 m). For the intermediate scenario (1.2 m SLR), the Corpus Christi Fire Station on North Padre Island (Corpus Christi Fire Department Station 15) and Nueces County Rural Fire Protection District 2 (mainland side of JFK causeway) are at most risk due to SLR in terms of distance to water (~150 m; Figure 20). About 28% of the fire stations in the CBBEP area lie within 1000 m of the 1.2 m SLR shoreline and 67% lie within 5000 m (Figure 21).

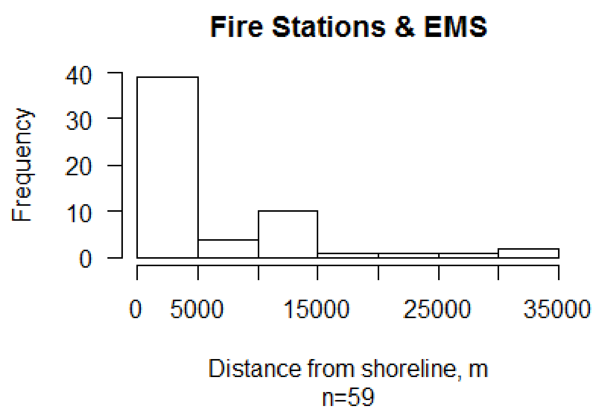

Figure 21. Frequency of fire station and EMS locations that fall within the 1.2 m SLR scenario.

Medical

Health care facilities include larger facilities such as hospitals and medical centers, as well as, smaller facilities such as family practices and health clinics. In the 6 county area there are 14 hospitals and medical centers and 32 smaller health care clinics. All health care facilities are not impacted by the highest SLR scenario (2.0 m). Two of the 13 hospitals and 5 of the 32 health clinics are less than 1000 m away from the projected 1.2m SLR shoreline (Figure 22).

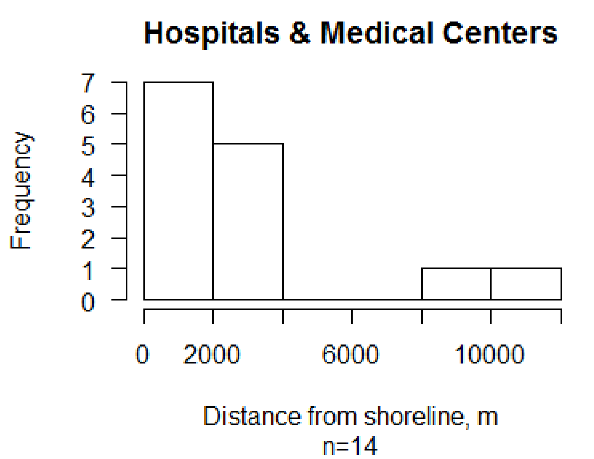

Figure 22. Distance of medical centers and hospitals to the 1.2 m SLR scenario shoreline.

Solid Waste

Solid waste facilities include landfills, recycling centers, and solid waste processing facilities (i.e. incinerators, composting). These data were gathered from the TCEQ which oversees waste permits[14]. There are 21 active facilities in the Coastal Bend area and none are at direct risk of SLR.

Public Water Supply and Wastewater treatment

Public Water supply facilities

There are two water treatment plants (WTP) in the 6 county area. The O.N. Stevens WTP is in Nueces County approximately 10 km from Nueces Bay (7 miles). The Stevens WTP produces on average 80 million gallons of treated water per day (~245.5 acre-foot) but has the capacity to process 167 million gallons[15]. The plant receives water from the Choke Canyon Reservoir and Lake Corpus Christi System (CCR/LCC) via the Nueces River. It also receives water from Lake Texana and the Colorado River via the Mary Rhodes Pipeline (Texana/MRP Phase II). These water supplies are owned by the City Corpus Christi through water rights and contracts with other river authorities. The Stevens WTP also delivers treated water to the San Patricio Municipal water treatment complex located in San Patricio County near Ingleside. The San Patricio water treatment complex also receives untreated water from Lake Texana via the Mary Rhodes Pipeline and untreated water from CCR/LCC system. The complex is managed by San Patricio Municipal Water District.

Both of these facilities are safe from SLR but may suffer from decreased water supply and increased temperatures. High temperatures reduce the efficiency of machines, and high temperatures increase the rate of evaporation. Since both plants utilize settling ponds as part of their operations, increased evaporation should be taken into account.

Wastewater treatment facilities

Data for wastewater treatment (WWT) facilities was provided by the City of Corpus Christi and 1 wastewater treatment plant was found (via internet) in Port Aransas. In Nueces County there are 7 wastewater treatment facilities (Figure 23). The Port Aransas Wastewater Treatment Plant is at risk from the intermediate SLR scenario however the rest of Nueces County WWT lie at least 300 m from the intermediate scenario shoreline.

[14] http://www.tceq.state.tx.us/permitting/waste_permits
[15] http://www.cctexas.com/government/water/general-info-water-qualitysupply/water-quality/treatment-process/index

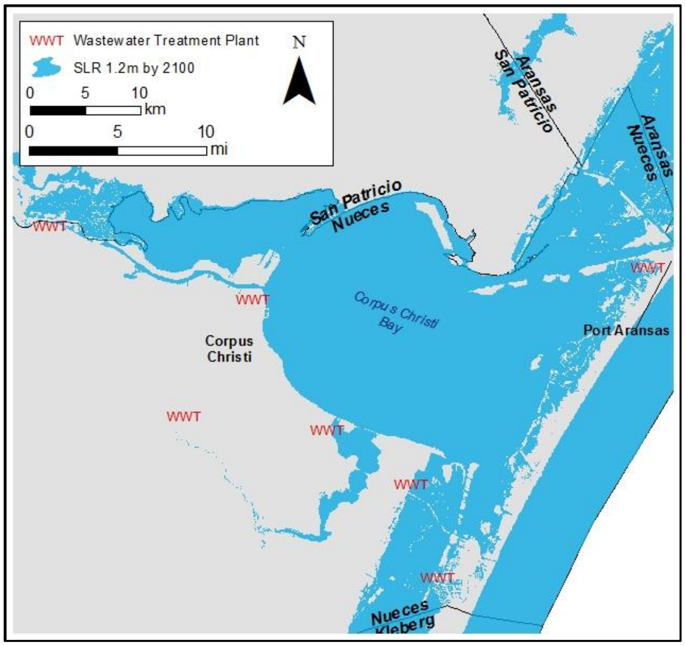

Figure 23. Location of wastewater treatment facilities (WWT) in Corpus Christi area.

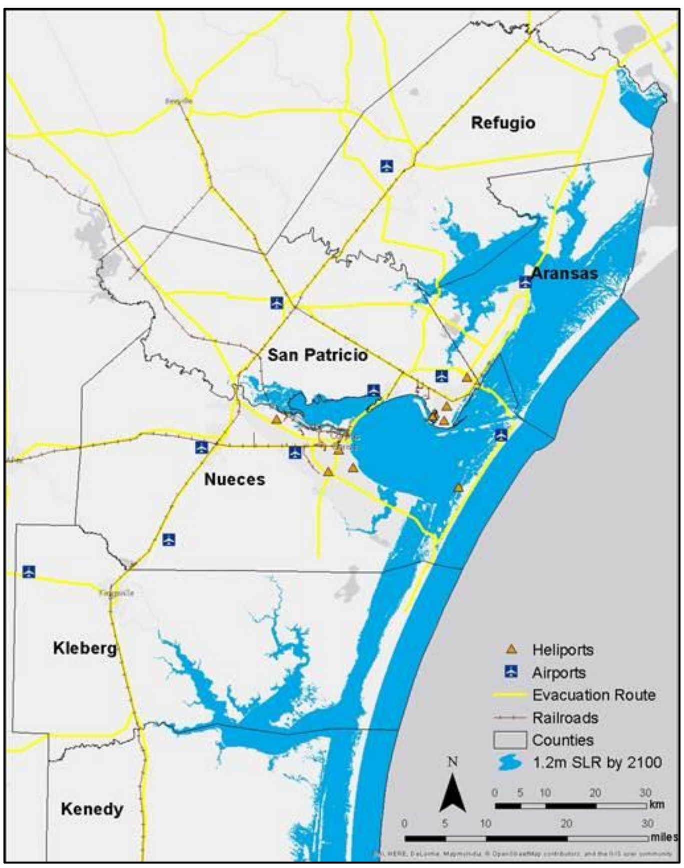

Figure 24. Transportation infrastructure in Coastal Bend coastal counties.

Transportation

Critical transportation facilities include roadways that are or support evacuation route roads, airports and heliports, and waterways. There are airport facilities located in every county except Kenedy (Figure 24). Mustang Beach Airport in Port Aransas is within the range of the mid-level SLR scenario. Additionally, 3 heliports are within the mid-level SLR scenario; 2 in San Patricio County along the Northern side of Corpus Christi Bay (Arco Ingleside Shorebase heliport; JBH Aerospace heliport), and one in Nueces County on Mustang Island (Mustang Island heliport).

SLR will also increase the likelihood of flood risks to those areas not directly affected by SLR. Storm surges will extend further inland and even high tides may interrupt normal traffic conditions. This phenomenon already happens in some parts of the county. For example, the Miami area in Florida is flooded during spring high tides (high tide right after a full or new moon) especially in the autumn when water temperatures are warmer (and thus water molecules expand) and other times when the tide is abnormally high (McNoldy 2015). Even if main roads or airports are not flooded, it is important to consider how the added traffic to "safe" transportation infrastructure will be impacted.

Due to the reliance of navigable waters, an increase in storm severity is likely to decrease port operations. Port of Corpus Christi, the 7th largest port in the nation based on cargo volume (American Association of Port Authorities 2014), is susceptible to the intermediate and high-end SLR scenario.

Energy Supply

Energy production

There are 11 power generation facilities in the Coastal Bend area. Kenedy County has 3 wind farms generating over 600 megawatts (MW) of clean, renewable energy that can power over 150,000 homes (Pattern Energy 2016; Ilberdrola Renewables 2016). There are 2 wind farms in San Patricio County owned by E.ON Climate Renewables North America that can generate 380 MW. There are also 6 wind turbines located on Port of Corpus Christi property, generating 9 MW of power.

In addition to the 6 wind farms across the region, there are 5 power plants using natural gas to generate electricity. In Nueces County, Topaz Power Group and Corpus Christi Cogeneration can generate over 1700 MW (3 facilities total in Nueces County).

Wind turbines located at the Gulf Wind farm in Kenedy County (Iberdrola Renewables) and the Harbor Wind farm at the Port of Corpus Christi are at risk to 1.2 m of SLR by 2100. In addition to SLR threatening coastal energy producers, increasing air and water temperatures decrease the efficiency of energy production (Wilbanks et al. 2007). Moreover, increasing temperatures will increase energy demands, potentially maxing out the available energy supply.

Economic activities

Weather-dependent industries like agriculture and tourism are obvious economic activities that are likely to feel the direct impact from climate change anywhere in the United States, but most industries are likely to see a change in demand regardless of dependency on weather. For example, there is likely to be an increase in demand for health care services as extreme weather such as heat waves become more prevalent. Knowlton et al. (2009) found a 5.0% increase in emergency room visits during the 2006 heat wave in the Central Coast of California (July 15 - August 1). Similarly, the demand for energy will rise as more households increase the use of air-conditioning. It is difficult to predict how the change in one market will impact another and even more difficult to quantify change. This section will focus on discussing how climate may impact leading industries qualitatively.

In general, coastal economies are at high risk to climate change impacts due to land based threats (i.e. higher air temperatures) and ocean-based threats. Sea level rise will encroach upon or inundate businesses, real estate and residences, infrastructure, and coastal attractions. The impacts of increased storm severity (storm surge, wind speed, wave impacts) will increase costly damages and interrupt business operations. The Gulf Coast (see Box 1) is projected to see an increase of $26 billion in losses by 2050 under the high scenario (Entergy 2010). Most of this loss is due to the continued development and economic growth in coastal areas. In fact, the coastal areas of Texas, Louisiana, Alabama, and Mississippi are reported to have over $2 trillion in asset value (2010 dollars) with much of this value from residential and commercial assets, and oil, gas, and electricity comprising much of the industrial assets.

Box 1 Gulf Coast Economic Assessment

In the 2010 report *Building a Resilient Energy Gulf Coast* (Entergy) the Gulf Coast areas of Texas, Louisiana, Alabama, and Mississippi were assessed for economic losses due to climate change. In this report, 3 assessments were used to project losses under different climate scenarios. Two of the assessments modeled climate change hazards (i.e. storm surge) and vulnerability (i.e. proximity to coastline), while the remaining assessment modeled value of assets over time. The Gulf Coast was reported to have over $2 trillion in asset value with expected growth to over $3 trillion by 2030. Most of this value is derived from residential and commercial assets, with industrial assets of oil and gas, and electricity being the other key sources of value. The report determined that currently $14 billion are lost annually, but this value is expected to increase to ~$26 billion (low-end scenario) to $40 billion (high-end scenario) by 2050. Much of this increased loss is due to the projected increase in frequency of extreme weather events (i.e. Katrina happening 1 in 40 years, opposed to 1 in 100 years) and the general increase of economic growth in a "risky" area.

The economic activity of the Coastal Bend area was assessed using data from the U.S. Census Bureau's County Business Patterns survey[16] (CBP) and the U.S. Bureau of Economic Analysis (BEA) Local Area Personal Income[17]. Both of these data sources use the North American Industry Classification System to classify business establishments based on the type of economic activity[18]. The CBP produces annual datasets that include the number of employees during the week of March 12 and the number of establishments per industry (2013). The BEA provides dollar amounts produced annually by a given industry (2014). The Industries assessed will be non-farm industries.

<u>County Business Patterns</u>

The industries that employ the most people on a per county basis are: Accommodation and Food Services, Health Care and Social Assistance, and Retail Trade. These industries employ more than 10% of the work force in all counties (with the exception of Kenedy[19]). In San Patricio County, Manufacturing (>15%) and Construction (10.47%) industries were also leaders in employment. In Refugio County, Construction (11.30%) and Mining, Oil and Gas Extraction (22.53%) industries also ranked among top employers.

<u>Personal Income by Industry & County</u>

At least 10% of personal income per county is provided by the Mining, Oil & Gas industry and the Construction industry in the Coastal Bend area[20] (Table 2). Retail Trade also significantly contributes to income in Aransas (17.86%) and Kleberg (14.77%) counties, and Accommodation and Food Services is also critical for income in Aransas County (10.27%). The Health Care industry in Nueces County contributes 13.75% of the county's total personal income.

[16] http://www.census.gov/econ/cbp/
[17] http://www.bea.gov/regional/index.htm
[18] http://www.census.gov/eos/www/naics/
[19] Kenedy county data was limited due to the low population and low number of businesses
[20] Kenedy county data was limited due to the low population and low number of businesses

Table 2. Non-farm personal income by county and industry from 2014 U.S. Bureau of Economic Analysis (BEA). Estimates of earnings are identified based on the 2012 North American Industry Classification System (NAICS). Data obtained from Table CA5N Personal Income by Major Component and Earnings by NAICS Industry[21].

Earnings by Industry							
		Aransas	**Kenedy**	**Kleberg**	**Nueces**	**Refugio**	**San Patricio**
Industry	***sub-industry***	in thousands					
Forestry, fishing, & related		(D)	(D)	$2,018	$10,022	$3,045	$11,142
	Forestry & logging	*$0*	*$0*	*$0*	*$198*	*$0*	*$568*
	Fishing, hunting, & related	*(D)*	*(L)*	*(D)*	*(D)*	*(L)*	*(D)*
	Support for agriculture & forestry	*(D)*	*(D)*	*(D)*	*(D)*	*$3,008*	*(D)*
Mining, oil & gas extraction		(D)	(D)	$56,103	$1,824,691	$66,441	$104,445
	Oil & gas extraction	*(D)*	*(L)*	*(D)*	*$1,164,714*	*$21,725*	*$27,514*
	Mining	*$1,243*	*$0*	*(D)*	*$57,384*	*$0*	*$2,835*
	Support for mining	*$32,219*	*(D)*	*$18,957*	*$602,593*	*$44,716*	*$74,096*
Utilities		(D)	(D)	$2,953	$97,152	(D)	$13,282
Construction		$44,228	$0	$37,700	$1,458,962	$21,523	$275,458
Manufacturing		$3,342	$0	$17,333	$932,786	$132	$167,626
Wholesale trade		$6,533	$0	$13,149	$541,779	(D)	$14,869
Retail trade		$52,243	(L)	$52,418	$710,033	$9,119	$81,318
Transportation & warehousing		(D)	(D)	$24,024	$524,236	$5,133	$41,935
Information services		$3,394	$0	(D)	$122,431	(D)	$8,573
Finance and insurance		$14,348	$0	$19,583	$361,810	$2,065	$19,916
Real estate		$10,029	(D)	$9,780	$226,803	$5,000	$9,946
Professional services		$24,385	(D)	(D)	$615,396	$2,992	$59,646
Management services		$0	$0	(D)	$82,268	$0	$2,338
Administrative services		$11,680	(D)	$9,708	$464,650	(D)	$35,861
Educational services		(D)	$0	(D)	$56,937	(D)	$1,835
Health care		(D)	(D)	(D)	$1,434,611	(D)	$60,904
	Ambulatory health services	*$13,592*	*(D)*	*$33,456*	*$728,890*	*(D)*	*$27,145*
	Hospitals	*$0*	*$0*	*(D)*	*$520,523*	*$0*	*(D)*
	Nursing & residential care facilities	*$10,276*	*$0*	*$7,097*	*$98,805*	*$4,350*	*$12,047*
	Social assistance	*(D)*	*(L)*	*$4,472*	*$86,393*	*(D)*	*(D)*
Arts, entertainment, recreation		$6,831	(D)	$1,416	$61,818	(D)	$3,399
Accommodation & food services		$30,057	(D)	$32,275	$466,337	(D)	$42,040
	Accommodation	*$10,109*	*(D)*	*$5,069*	*$88,240*	*(D)*	*$10,060*
	Food & drinking services	*$19,948*	*(D)*	*$27,206*	*$378,097*	*$4,872*	*$31,980*
Other services		$28,173	$2,013	$31,500	$440,479	$5,481	$55,825
Total non-farm		**$292,573**	**$2,013**	**$354,985**	**$10,433,201**	**$135,634**	**$1,010,358**
Population (persons)		24972	400	32190	356221	7302	66915
(D) Not shown to avoid disclosure of confidential information							
(L) Less than $50,000							

[21] http://www.bea.gov/itable/

From these data we have identified the following industries as critical for the Coastal Bend area:

- Mining, Oil & Gas
- Construction
- Accommodation and Food Services (Tourism)
- Retail Trade
- Health Care

Oil & Gas

The Oil & Gas industry in the Coastal Bend area is at most risk from SLR and storm-related impacts. Damages from storms may make the facilities inoperable, disrupting the means of supply and distribution of oil and gas. In 2005, when Hurricane Katrina hit the Gulf Coast, gasoline prices skyrocketed due to the reduced production of the Gulf oil and gas industry. Nineteen percent of the Nation's oil production was affected by this one extreme weather event. As stated earlier, industries are often interrelated which is evident when comparing the Nation's economic growth before and after Katrina. The Nation's Gross Domestic Product growth went from 4.1% in the 3rd quarter to 1.7% in the 4th quarter, after Katrina hit (Economic Statistics Administration 2006).

Since all counties rely on the oil and gas industry for employment, all counties are at risk to economic hardship due to an interruption in oil and gas economic activities. Specifically, Refugio County is at the highest risk as almost 50% of personal income relies on the oil and gas industry.

Construction

Construction is likely to grow from the continual surge of economic growth and influx of the population near coastal areas. Communities that are looking to become resilient to climate change may choose to replace aging infrastructure, raise or move roads, or reinforce seawalls; all of which will require construction. As the population moves towards the coast, construction will follow to develop the land. Moreover, construction will be needed to rebuild areas damaged by storm events. However, construction is a weather-dependent industry and will also be impacted by the changing climate. With temperatures increasing up to 5°C by 2100, there may be many days that are unsafe to work due to the heat index, reducing personal income and profitability of this industry. Additionally, more employers may have to pay workers' compensation when their employees work in harsh conditions and suffer from heat stroke or other injuries. Alternatively, an employer could reduce worker exposure by increasing the number of employees.

Health Care

Health care is not likely to decrease due to climate change. The most critical ways this economic activity will be affected is by damages to the infrastructure and damages to the workers homes which could prevent them from working. Health care may see a drastic increase in demand as temperatures rise and heat-related illnesses increase, more severe storm events inflict injury and spread disease, and as warmer waters allow pathogens to thrive.

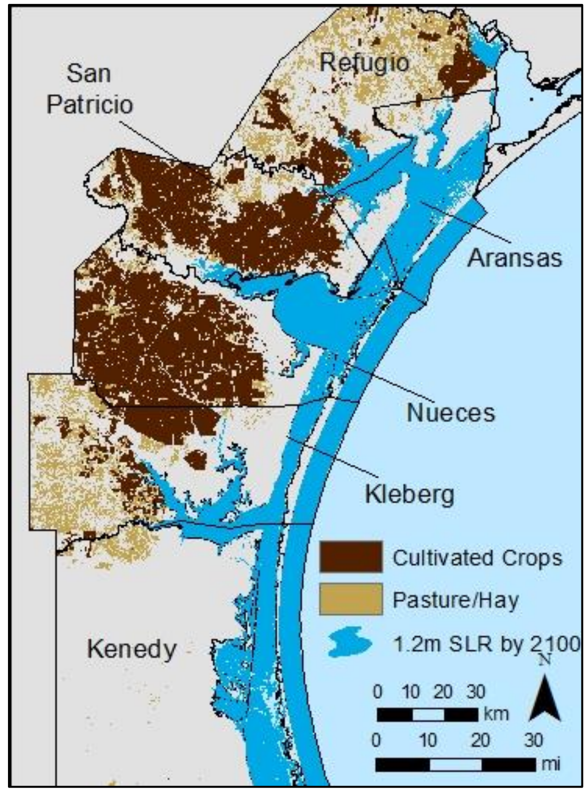

Figure 25. Cropland in coastal counties of the Coastal Bend region in Texas. Land cover extracted from the National Land Cover Dataset (Homer 2015).

Agriculture

Agriculture is heavily influenced by weather patterns and climatic conditions. Agriculture in the Coastal Bend area consists of crops (mostly cotton, sorghum, and corn), livestock such as cattle, and rented crop or pastureland. Based on the number of acres covered by a crop, sorghum and cotton are the dominating crops and largely confined to San Patricio and Nueces counties. Farming is critical in Kenedy (18% of county earnings), Kleberg (~17%), and San Patricio (13%) counties (Bureau of Economic Analysis 2014).

The Coastal Bend region is projected to see an increase in crop yields by 2030 for cotton, corn, and sorghum based on global climate models (see Reilly et al. 2002; McCarl 2011). Moreover, yield variability (a measure in the stability of a crop over time) is projected to decrease for cotton and sorghum by 2090 (Reilly et al. 2003). Recent research suggests that crop yields will fare better under the high scenario of this assessment (unchecked greenhouse gas emissions) than the low scenario (Figure 26; Reilly et al. 2013). While GHG emissions seem almost beneficial, the damaging impacts of ozone associated with unchecked GHG emissions may prove have an overall negative impact on crop production.

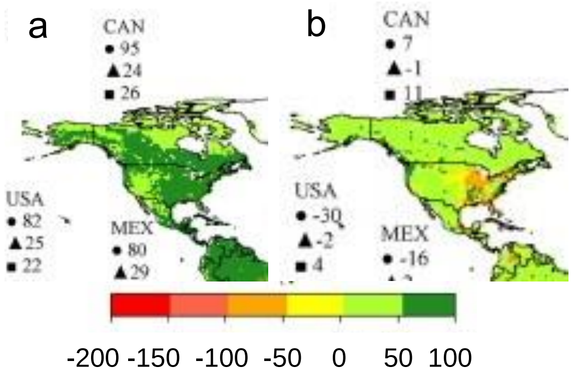

Figure 26. Change in crop yield under a) climate change and increased GHG emissions-high scenario, and b) GHG emissions capped at 550ppm-low scenario. The high scenario yields an 82% increase for crop yield and the low end scenario yields a 32% decrease in crop yields. Figure adapted from Reilly et al. 2013.

Costs of production may increase for farmers as water availability is reduced from drought conditions and as crop pests shift habitable ranges.

Tourism

Accommodation and food services, as well as, retail trade industries rely on a stable local economy and the influx of visitors attracted to the area. NOAA's Office for Coastal Management produces easily digestible statistics for ocean-related employment for all counties along the coastal U.S[22]. Tourism and recreation employ over 30% of ocean-related workers in all counties with 100% of ocean-related jobs falling under the tourism and recreation category in Kenedy and Kleberg counties.

The Coastal Bend area attracts a variety of visitors interested in the beaches, wildlife, and culture of the coast. With climate change, this area may become undesirable for many reasons. The air temperatures and humidity may become too high for visitors to enjoy outdoor activities, increased storm activity (wave action) and SLR may degrade or destroy valuable coastal habitats, and decreased water quality from higher temperatures and reduced freshwater input may decrease popular fisheries. Resorts, hotels, and other vacation properties located along the coastline will either have to armor their shoreline to protect against SLR and wave exposure or resort to moving landward. Beaches may have to be managed through costly means of beach replenishment as SLR and erosion damage the shorelines.

[22] www.coast.noaa.gov/snapshots/

Cultural Resources

The Coastal Bend has a rich historical presence dating back to the 16th century. Since then the Coastal Bend area has switched hands between different nations: Spain (1500's-1820), Mexico (1821-1836), and the United States (1845-present). With the Coastal Bend area riddled with aspects that create the region's "essence" like the undeveloped beaches of Padre Island, the King Ranch in Kenedy County, historical pirates of Port Aransas, and the academic institutes, it is important to assess the potential impacts that create a region's presence. The National Register of Historic Places and the Texas Gazetteer compile names of historic places, both physical and cultural.

Historic places

There are 30 items on the National Register of Historic Places in the study area. There are 2 places within 100 meters of the intermediate SLR scenario, each located along bays in different counties. In Refugio County, the John Howland Wood House (built in 1875) lies along the shoreline of Copano Bay, less than 70 m from the shoreline. Nueces County is home to the USS Lexington, originally a World War II aircraft carrier (1941), a decommissioned battleship of the United States Navy. It is now a museum ship and National Historic Landmark

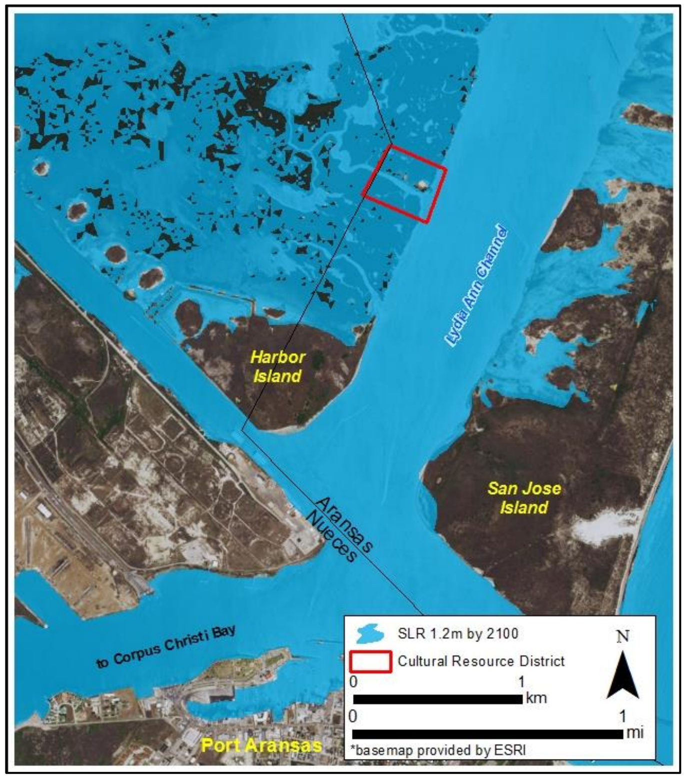

Figure 27. Lydia Ann Aransas Pass lighthouse (property outlined in red) becomes inundated under 1.2 m SLR scenario (intermediate scenario).

afloat in Corpus Christi Bay.

Lighthouses

There is one lighthouse in the Coastal Bend area. The Aransas Pass/Lydia Ann Lighthouse lies along Nueces and Aransas county borders on Harbor Island (Figure 27). The lighthouse was built in 1855 and was built to mark safe passage to the mainland through Aransas Pass. Over time, the Aransas Pass shifted south about a mile and the lighthouse was deactivated in 1952 when a new light was installed at the Coast Guard Station in Port Aransas. The lighthouse is privately owned and remains a historical and cultural site. While the Harbor Island area is protected by San Jose Island, is susceptible to storm surge from even Category 1 hurricanes at present, without added SLR. The lighthouse and the keeper's quarters are projected to be completely inundated under the intermediate and high-end SLR scenarios.

Other community resources

Churches and cemeteries bring a sense of community and comfort to the citizens they serve. There are 2 cemeteries located on St. Mary's Road near Copano Bay that are at risk to the intermediate SLR scenario. Two churches are at risk to 2.0 m SLR by 2100 in Rockport: First Presbyterian Church, and Salt Lake Baptist Church.

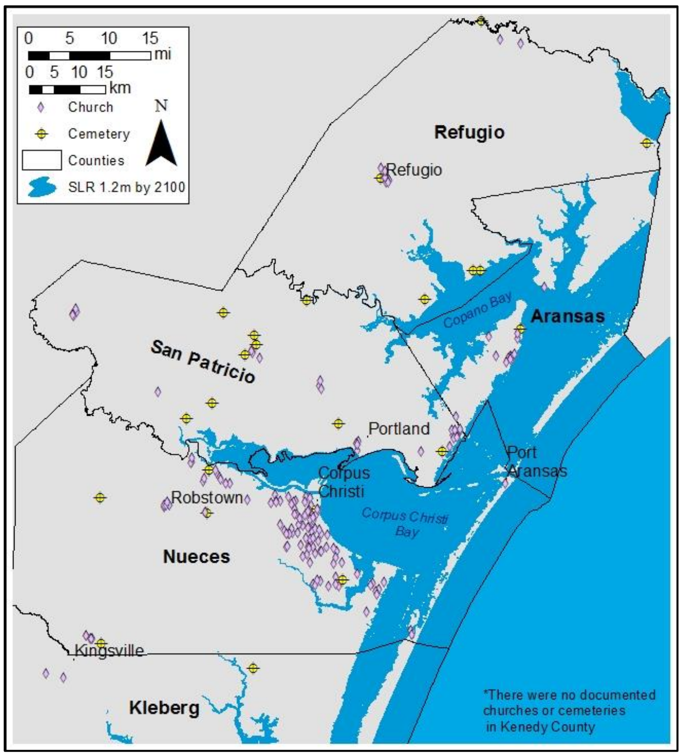

Figure 28. Locations of churches and cemeteries in the coastal counties in the Coastal Bend area.

Public schools, while obviously critical to education, also often serve as storm shelters and refuge centers for displaced citizens. Educational facilities were derived from the Texas Education Agency (TEA) and the Texas Gazetteer (mainly universities and private schools). There are over 200 schools in the Coastal Bend area with a majority of schools in the City of Corpus Christi. Texas A&M University – Corpus Christi is a University located on Ward Island on the Southwest side of Corpus Christi Bay (Figure 29). The complex of educational facilities found on Ward Island (including an elementary school for children of ages 3 through 5th grade[23]) is within 100 m of the intermediate SLR shoreline. Texas A&M University – Corpus Christi leads local science on SLR and are aware of the potential impacts to the campus. While most schools in the Coastal Bend area are not as risk to the intermediate SLR scenario, there are 30 schools within 1000 m of the intermediate SLR scenario shoreline with 27 of these schools within 1000 m of the current shoreline. 27 schools within 1000 m of the current shoreline. A majority of these facilities (over 70% for both the current shoreline and 1.2 m SLR shoreline) are public facilities.

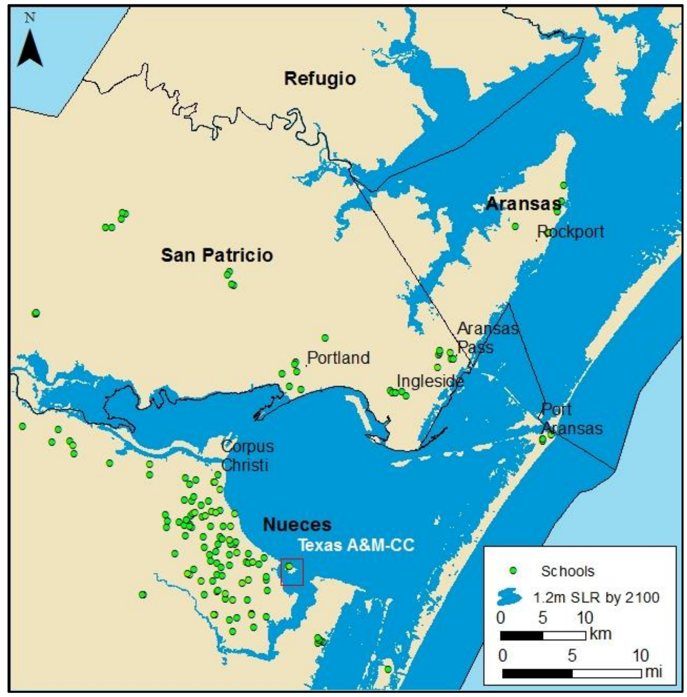

Figure 29. School facilities in close proximity to the intermediate SLR scenario. Texas A&M Corpus Christi (Texas A&M-CC) is at risk to SLR.

[23] http://ecdc.tamucc.edu/

Human Health

Direct Stresses from Higher Temperatures

The direct stress from higher temperatures will increase the risk of heat-related illnesses (heat cramps, heat exhaustion, and heatstroke) and mortality. In Nueces County there have been 13 deaths since 1999 due to excessive natural heat (Centers for Disease Control 2015b). These deaths are preventable.

Direct stress from higher temperatures will impact everyone but the impact will vary based on a variety of input factors. Factors that affect vulnerability to heat-related illnesses and deaths are age, health status, income, and land cover (Reid et al 2009; Manangan et al. 2014).

The elderly and people with pre-existing health complications have higher health risks associated with severe heat. Elderly people, defined as persons 65 years of age and older, may have a decreased ability to maintain physiological equilibrium and a misconception of ambient temperature. Pre-existing health conditions such as diabetes, cardiovascular issues, renal diseases, and diseases of the nervous system may worsen with higher temperatures. People living below the poverty line are at risk to increasing temperatures because

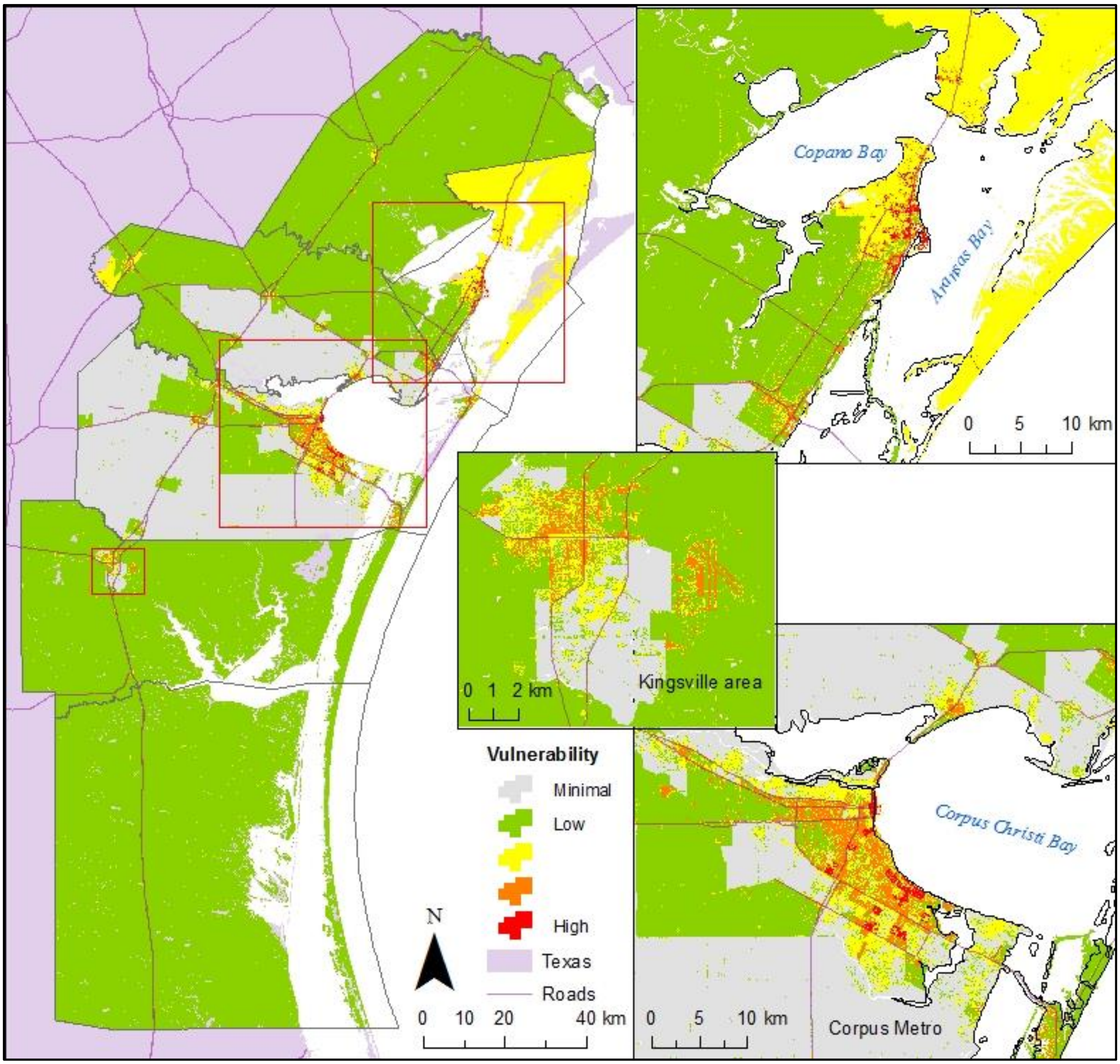

Figure 30. Vulnerability to higher temperatures based on the percent of the population over 65 and the percent of impervious surface. Hotspots in the CBBEP coastal counties can be observed in the Corpus Christi metro area (bottom right), Kingsville (middle), and Rockport (top right) area.

they may not have the resources to manage heat stress (i.e. access to air conditioning, medical assistance). Lastly, vegetation coverage has been shown to influence surface temperatures with urban areas consisting of sparse vegetation being associated with higher surface temperatures. Harlan et al. (2006) showed that communities with high housing density, sparse vegetation, and no open space are at higher risk to heat stress. As urbanization increases, it will be important for communities to consider land cover types when planning a community in order to reduce heat stress.

Overlay analysis of these vulnerability variables will help communities identify areas of high risk to heat-related morbidity/mortality (Figure 30). In the Coastal Bend region approximately 17% of population is 65 years or older with Aransas County having the highest percentage of elderly of around 27% (US Census Bureau 2015). Occupation or the amount of time a person spends outside may also elevate a person's risk to heat exposure. Farmers, construction workers, fisherman, and outdoor enthusiasts are all examples of people that may have to take special precautions. Additionally, exercising in the heat increases risk to heat related illness and death. While exercise and outdoor activities are optional, the reduction in activity may dampen quality of life in the Coastal Bend region, as well as, the economy as tourism and recreation are a large part of the region's economy.

Freshwater Shortage

As precipitation patterns change and populations continue to grow, freshwater will increase in demand. The Natural Resources Defense Council (NRDC) commissioned a National assessment of water availability by the year 2050. The study projected water demand by focusing on population growth and how growth affects municipal water demand and water withdrawals for energy generation. The study found that under a business-as-usual scenario (high emissions), the majority of Texas will be at extreme risk for water shortages[24] (Roy et al. 2012). The counties of the Coastal Bend region are at high risk for water shortages (scale ranging from extreme to low) except San Patricio and Kleberg counties which are at extreme risk[25].

In coastal areas SLR and storm surge also threaten to compromise freshwater supply (Georgakakos et al. 2014). As sea level rises, saltwater invades freshwater areas threatening surface and groundwater supplies. In addition, fresh water sources are further compromised as storm surge inundates coastal lands and thus surface water supplies. Moreover, as air temperatures increase so will evaporation rates further decreasing available freshwater resources. All these compounding factors may challenge the reliability of water supplies for Coastal Bend residents and businesses.

Water and food-borne illnesses

In the U.S., most water and food-borne diseases are gastrointestinal (Portier et al. 2010) and are caused by microorganisms (bacteria, viruses, and protozoa) contaminating resources. In Texas during 2013, there were 351 cyclosporiasis cases (an intestinal infection caused by a parasite that is transmitted through food and water that has been in contact with feces), making Texas the state with the highest number of incidences in the United States (Centers for Disease Control 2013). In general, these diseases are more common when temperatures are higher (potentially because more people are in water for recreational purposes). Research suggests that presence of waterborne diseases is positively correlated with temperature (Onozuka et al. 2009) and certain foodborne pathogens (*Vibrio*, *E.coli*, *Salmonella*) are also positively correlated with temperature (Kim et al. 2014; Akil et al. 2014). Additionally, heavy precipitation deteriorates surface water quality as runoff contains pesticides, fertilizers, and animal waste and has been linked to outbreaks of waterborne diseases (Rose et al. 2000).

Water pollution and toxins

Water quality is likely to decrease with climate change. As air temperatures increase, so will water body temperatures. A common measure of water quality is the concentration of dissolved oxygen (DO). Since warm water holds less dissolved oxygen, warmer waters are likely to decrease in water quality. Additionally, as DO decreases with increasing temperatures, the flora and fauna of the water body may become stressed and potentially die.

Heavy rain events also have the potential to diminish water quality as it is likely to cause runoff. Runoff can increase delivery of sediments, nutrients, pesticides, herbicides, animal waste, pathogens, and other pollutants to surface waters allowing the concentrations to reach hazardous levels. If runoff reaches high velocities, it also can cause erosion adding additional particulates to the water column and potentially altering the hydrology (U.S. Geological Survey 2015). As urbanization grows and more vegetated land cover will be replaced by impervious surfaces, runoff increases and less water infiltrates into the ground (Paul & Meyer 2001). This high amount of runoff increases the chances of flooding which would allow more surface pollutants to enter water bodies. Pollutants and other impurities will continue downstream until they reach large lakes, estuaries, and eventually the ocean where they have the potential to cause problems, such as harmful algal blooms (Heisler et al. 2008).

Climate change amplifies factors that contribute to decreased water quality and many of these factors interact to create even bigger issues. In addition to increased runoff from intense precipitation events and decreased DO from warmer temperatures, the dry period between precipitation events is expected to increase, increasing the potential for drought conditions. Drought conditions combined with warmer temperatures concentrate particulates in water bodies as water is removed from the system by natural processes and higher evaporation rates. Moreover, drought conditions reduce flow

[24] http://www.nrdc.org/globalwarming/watersustainability/files/WaterRisk.pdf

[25] http://www.nrdc.org/globalWarming/watersustainability/

rates and increase coastal water salinities as freshwater input is reduced (U.S. Environmental Protection Agency 2015).

Likewise SLR and storm surge have an additive impact on coastal areas. The increase of storm surge extent due to SLR will increase the damage to coastal infrastructure and habitats, adding more sediments and pollutants to water bodies. If storm surge is able to reach waste facilities or floods sewage systems, surface waters could be contaminated with untreated human, industrial, and commercial waste.

Decreased air quality

The Environmental Protection Agency (EPA) sets air quality standards for pollutants considered harmful to public health. There are six principle pollutants (criteria pollutants) including ozone (O_3), particulate matter, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and lead (Pb)[26]. The sources of these pollutants mostly stem from emissions from industrial and electrical facilities, and motor vehicles, but natural sources also exist. For example, particulate matter can be the smoke and debris from wildfires or the dust associated with dried out soils. Some pollutants chemically react to form other pollutants; however we will focus on primary pollutants that are likely impacted by climate change, specifically ozone and particulate matter (Kinney 2008).

Ozone, specifically ground-level ozone, is formed when air pollutants (volatile organic compounds-VOCs and nitrogen oxides-NOx) react with sunlight. Ozone is more likely to reach hazardous levels in the summer or warmer months of the year because ozone formation increases with greater amounts of sunlight and higher air temperatures. Since surface temperatures are projected to increase up to 5.6 °C (10 °F), detrimental effects of ground-level ozone will likely increase. Holding current emissions constant, ozone concentrations are projected to increase by 5-10% by 2050 (Kinney 2008). Ozone effects human health by decreasing lung function and inflaming lung tissue. Effects on health increase for people with lung disease or asthma, children, the elderly, and people who exert themselves outdoors.

Particulate matter are extremely small particles suspended in the air column that can be inhaled or cause reduced visibility. With shifts in precipitation patterns, we are likely to see longer dry periods which could lead to drought conditions. Drought conditions increase the likelihood of wildfires which deposit particulate matter into the air in forms of smoke and debris. Moreover, drought conditions will increase the availability of dry soils to be swept into the air column as dust. “Fine particles”, those with diameters 2.5 μm and smaller, can not only be inhaled but can even enter the bloodstream, causing premature death in people with heart or lung disease, nonfatal heart attacks, and irregular heartbeat. Other health effects caused by particulate matter are decreased lung function and aggravated asthma. People most vulnerable to particulate matter pollution are people with heart or lung diseases, people with asthma, children, and the elderly. More information can be found on the EPA website, http://www3.epa.gov/airquality/particlepollution/health.html.

In addition to pollutants, airborne allergens also affect air quality in terms of human health. Airborne allergens or aeroallergens largely stem from pollen and molds which trigger allergies, asthma and other respiratory diseases. Increased temperatures are likely to cause an earlier onset of pollen season and potentially increase the length of the season due to a longer growing season (Ziska et al. 2008a). Higher temperatures also increase air moisture concentrations, creating conditions likely to cause mold growth. In addition to increasing temperatures, research suggests that elevated CO_2 levels may increase pollen production and allergen potency (Ziska et al. 2000; Singer et al. 2005).

Increased storm severity

In addition to the 13 preventable deaths from excessive heat, the CDC reports an additional 2 deaths resulting from flood or storm events (Centers for Disease Control 2015b).While this number is low, it is expected to increase under future climate change conditions.

[26] http://www3.epa.gov/airquality/urbanair/

Water Resources

In Texas, water resources are managed by a number of agencies in accordance to State and Regional planning documents that are approved by the Texas Water Development Board (TWDB). There are 16 regional water planning areas in Texas that develop water management plans specific to their region. Water planning in Texas has to consider the different regulations and laws that consist of each water regulation class.

Water regulation is split up into 5 classes: surface water, ground water, water quality, drinking water, and interstate waters (TWDB 2012). Surface waters are managed by the TCEQ which grants permission to use water to different groups and individuals. Water rights stem from the riparian doctrine and prior appropriation doctrine which claimed that landowners who live on a water body are allowed to use the water supply. Today water rights are recognized by TCEQ based on a priority system which gives priority to a user based on when the water claim was first made (date). TCEQ may issue new water rights if the new claim complies with the associated regional and state water plan; however there is little water remaining for appropriation (TWDB 2012).

Ground water usage is managed by either the landowners above it or the groundwater conservation disctrict (GCD). Landowners have full rights to the groundwater on their land unless the land lies within a GCD (Box 2). Since 1951, GCDs have locally managed groundwater withdrawal. Today, GCDs cover a majority of the state. There are 100 GCDs in Texas with 4 (Refugio, Kenedy, Corpus Christi, San Patricio) in the scope of this assessment[27] (TCEQ 2016). The Gulf Coast Aquifer (GCA) provides the groundwater for this region.

Box 2 Groundwater Conservation Districts

Groundwater Conservation Districts are political entities that manage and protect groundwater at a local level. By law, a GCD is required to develop a groundwater management plan that ensures efficient use of groundwater, prevents contamination, prevents subsidence, addresses conservation and natural resource issues, and addresses drought conditions. GCDs also permit new wells and monitor wells for water quality.

Water quality and public drinking water is managed by TCEQ. Guided by federal and state regulations, TCEQ sets water quality standards based on the purpose of the water use (i.e. recreation, drinking water, aquatic life). If a water body becomes impaired (does not meet set standards for use), TCEQ develops a restoration plan and potentially a total maximum daily load (TDML) which sets the maximum amount of pollutants a water body can receive (TWDB 2012). Drinking water standards limit the amount of contaminants in the water supply and the taste, color, and odor. Additionally, TCEQ is responsible for delineating water or sewer utility service areas and licensing operators that supervise a public water supply system.

Since the study area is split between 2 water planning regions, Region N (Coastal Bend) will guide the rest of the section as it holds a majority of the selected counties (Refugio county is within Region L since it is bordered by the San Antonio River). Region N has 4 wholesale water providers: City of Corpus Christi (City), San Patricio Municipal Water District (SPMWD), South Texas Water Authority (STWA), and Nueces County Water Control and Improvement District #3 (WCID). The City of Corpus Christi is the primary provider of surface water in the region. The City receives water from its own water rights on Choke Canyon Reservoir/Lake Corpus Christi system (CCR/LCC), water rights located on the Colorado River via the Mary Rhodes Pipeline-Phase II (MRP Phase II), and through a contract with Lavaca-Navidad River Authority that provides water from Lake Texana (via Mary Rhodes Phase I Pipeline). These water supplies are jointly named the CCR/LCC/Texana/MRP Phase II System. The City of Corpus Christi then sells water to SPMWD that is then treated at the San Patricio Water Treatment Plant (WTP), and also sells treated water to the STWA. Nueces County WCID #3 receives water from its own run-of-river rights in the Nueces Basin. To find more information about Texas water management, visit the Texas Water Development Board website[28].

Water Supply Plans

TWDB issues population growth and water demand projections so regional water planning groups (WPG) can develop water supply plans. Water supply plans assess the budget between projected water demand and current water supply, addressing deficits that may arise by formulating alternative water strategies. The Coastal Bend region produces water supply plans by county and user group. The following user groups are assessed:

- Municipality
- County-other (rural areas)
- Manufacturing
- Steam-Electric
- Mining
- Irrigation
- Livestock

For the 2016 Coastal Bend Regional Water Plan (CBRWP), water supply plans were formulated to 2070.

27 http://www.tceq.state.tx.us/assets/public/permitting/watersupply/groundwater/maps/gcdmap.pdf

28 http://www.twdb.texas.gov/

Aransas County

Water is provided to the municipalities (Aransas Pass, Fulton, Rockport) and rural areas by SPMWD (CCR/LLC/Texana/MRP Phase II System). Manufacturing, mining and livestock user groups rely on groundwater from the GCA. In Aransas County, there are no foreseeable shortages in water supply, however it is suggested that additional water conservation actions be considered for the cities of Fulton and Rockport. Irrigation and steam-electric user groups do not exist in Aransas County.

Kenedy County

Kenedy County water demands are met by groundwater from the GCA. No shortages in water supply are projected in this area, however additional water conservation measures are recommended.

Kleberg County

The City of Kingsville receives treated water from the STWA and also pumps groundwater from the GCA. Ricardo Water Supply Corporation in Kleberg County, a small water distributor, is also provided water supply from STWA. While water demand grows in the city, no shortages are projected for either user group. There are also no projected shortages for mining, irrigation, and livestock user groups, all of which depend on groundwater from the GCA.

Nueces County

The City of Corpus Christi meets water demands with its own water rights in the CCR/LCC/Texana/MRP Phase II System. This provides the city with enough water to sell water to SPMWD, STWA, and other industrial user groups. While there are no shortages projected for the municipality, additional water conservation is recommended.

The cities of Agua Dulce, Bishop, and Driscoll all receive treated water from STWA that comes from the CCR/LCC/Texana/MRP Phase II System. There are no projected shortages for any of these cities, however additional water conservation is recommended for Bishop. The City of Robstown purchases treated water from Nueces County WCID #3 which has run-of-river rights from the Nueces River. Due to limited water supply in drought conditions, WCID #3 may not have enough supply to meet Robstown needs. To address Robstown water shortage projected from 2020-2070, a small reservoir is recommended for Nueces County WCID #3.

Port Aransas is provided treated water from Nueces County WCID #4 which contracts with City of Corpus Christi and SPMWD to purchase treated water from the CCR/CCL/Texana/MRP Phase II System. While no water shortages are projected, it is recommended by the RWPG that additional water conservation measures be established.

Manufacturing and steam-electric water needs in Nueces County are met by surface water supply from the City of Corpus Christi (CCR/LLC/Texana/MRP Phase II System) and groundwater supplies from the GCA. Water shortages are projected as early as 2050 and are attributable to raw water and water treatment plant constraints. The water supply plan for these user groups are: water conservation, water treatment plant improvements (O.N. Stevens), reclaimed water, off-channel reservoirs, and desalination of seawater and brackish groundwater. The mining user group receives water from the City of Corpus Christi and groundwater from the GCA. Mining has no projected water shortages.

Irrigation and livestock water demands are met with groundwater from the GCA. No water shortages for irrigation or livestock are projected in Nueces County.

San Patricio County

The cities of Aransas Pass (spread over San Patricio, Aransas, and Nueces counties), Gregory, Ingleside, Ingleside on the Bay, Odem, Portland and Taft, and rural areas of San Patricio County are all provided water from the SPMWD (CCR/CCL/Texana/MRP Phase II System). There are no projected water shortages in these cities, however Gregory and Portland are recommended to take additional water conservation actions. Lake City & Sinton both receive groundwater from the GCA and also do not have projected shortages, but Sinton is recommended to adopt water conservation strategies. The City of Mathis purchases raw water from the City of Corpus Christi (CCR/CCL/Texana/MRP Phase II System) and there are no shortages anticipated.

Manufacturing in San Patricio County is provided water from SPMWD and groundwater from the GCA. Water shortages are projected as early as 2020. The water supply plan for this user group is: water conservation, water treatment plant improvements (SPMWD), reuse pipeline (Portland), off-channel reservoirs, and seawater and brackish groundwater desalination. These additional water demands will most likely be jointly accomplished through SPMWD and the City of Corpus Christi.

Mining and livestock meet water demands through groundwater supplies from the GCA. There is no projected shortage in water supply for these user groups. Irrigation also receives water from the GCA and is advised to drill additional wells to meet future water demands.

Refugio County

Refugio County is within Region L WPG. The cities of Refugio and Woodsboro along with the rural areas of the county receive groundwater from the GCA. There are no projected shortages, however water conservation is recommended for the municipal user groups. Mining, irrigation, and livestock also receive groundwater from the GCA and also have adequate water supplies for the planning period. Manufacturing and steam-electric user groups do not exist in Refugio County.

Threats to water supply

While the plan is guided by the principals of protecting water as a natural resource, it fails to incorporate future climate change impacts that affect water supply. Rising sea levels could lead to surface water contamination or saltwater intrusion of groundwater sources. Many smaller communities and user groups in the Coastal Bend Regional Water Planning Group (CBRWPG) are largely dependent upon groundwater from the GCA (Kenedy County, Refugio County; mining, livestock, and irrigation user groups). Due to the threat of saltwater intrusion, alternative water supplies should be considered for these areas.

A majority of the CBRWPG area relies on surface water from the CCR/LCC/Texana/MRP Phase II system. As stated in previous sections, higher temperatures lead to higher evaporation rates which will in turn reduce surface water supplies. In order to properly project water supply, higher evaporation rates should be taken into account

Additional variables should be considered when projecting future water supply. For example, applying higher evaporation rates to future surface water supplies would promote a more conservative plan and ensure adequate water supply. With the large uncertainty in climate impacts and the large costs associated with varying water supply strategies, stringent water conservation may prove the most reliable strategy.

Coastal Resources

Erosion

Texas shorelines are eroding at an average rate of 0.7 m (2.3 ft) per year with some locations losing up to 9.1 m (30 ft) per year (Texas General Land Office 2015). The majority of the Coastal Bend shorelines have moderate to high erosion rates. Around 30% of shorelines have high erosion rates (over 1 meter per year) in the Coastal Bend area with a majority of high erosion rates happening on the southern half of Mustang Island to the Northern portion of Padre Island (Thieler & Hammar-Klose 2001). Coincidentally, most of the areas of high erosion are protected by state or federal entities (i.e. Mustang Island State Park). Communities at high risk to erosional forces are North Padre Island (Padre Isles) and Flour Bluff.

Climate change is likely to increase the rate of erosion in coastal areas. Higher sea levels will increase the land area subject to wave action, heavier rainfall events will increase soil loss due to runoff, and warmer temperatures may decrease soil moisture enough to make it susceptible to wind (Ziadat and Taimeh 2013). The combination of rising sea levels and increased storm severity may lead to increased overwash on barrier islands, further depleting the shoreline of sand.

Viable and healthy salt marshes, which are allowed to migrate naturally with rising sea levels, provide non-structure flood control for coastal and human protection, reduce coastal erosion and provide the ecological structure needed to maintain additional coastal habitats, including seagrass beds, freshwater marshlands and even coastal prairie grasslands. All of which are important factors that influence coastal resiliency. Brenner and Thompson (2013) suggest that SLR impacts should be incorporated into ongoing conservation planning and management activities within the Corpus Christi Bay region. Specifically, key parcels of land adjacent to existing management areas could be acquired and/or sustainably managed to allow for the landward migration of vulnerable marsh habitats. Between 2004 and 2100, over 17,000 acres of land are predicted to contain critical salt and freshwater marsh refuge. These areas should be prioritized for conservation and/or acquisition and we highlight priority areas that are adjacent to existing federal and state management areas.

Inundation

Flooding in the Coastal Bend area can arise from rainfall events, abnormally high tides, and storm surges.

Rainfall and Tidal Flooding

The increase in severity of precipitation events will likely lead to a higher frequency of floods, particularly flash floods. Urban areas are more vulnerable to flooding and "flash" flood events due to the high percentage of impervious surfaces.

"Coastal County Snapshots" provide quick information to stakeholders and interested parties on flood exposure in coastal counties[29]. Aransas County has the highest percentage of the population in a FEMA floodplain based on the 2009 – 2013 American Community Survey (24%). However, Nueces County has developed the most land in FEMA floodplains. Without added infrastructure, we can expect these counties to suffer the worst flood losses.

Storm surge

Rising sea levels will expand the area subject to storm surge, increasing the odds of damaging floods. Climate Central, a group of scientists analyzing the impacts of climate change, produced a report stating that under the intermediate SLR scenario a 100-year flood will become 20% more likely to

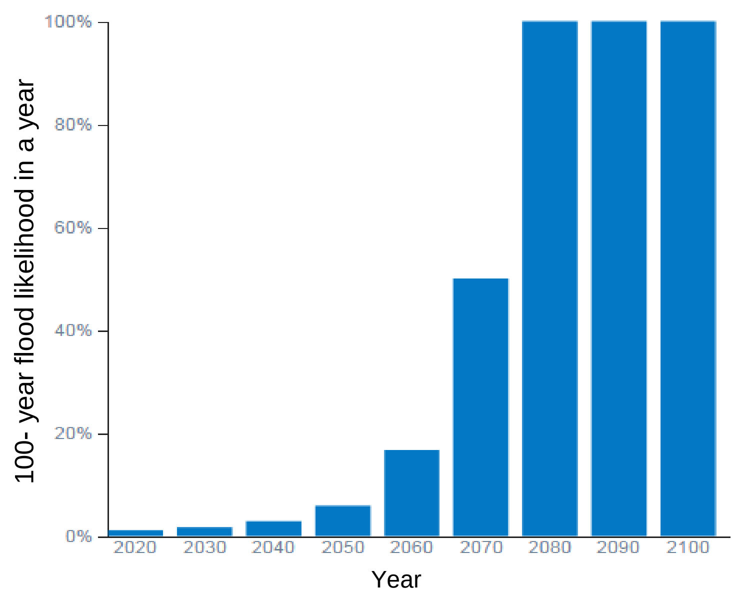

Figure 31. Likelihood of a 100-year flood occurring in Rockport, Texas based on intermediate SLR scenario. Data and figure obtained from Strauss et al . 2014.

[29] https://coast.noaa.gov/snapshots

happen by 2030 in Rockport, Texas (Strauss et al. 2014). By 2080, the likelihood increases to 100% (Figure 31). Under 2 m of SLR, the annual risk is 100% starting in 2060[30].

Oak Ridge National Laboratories (ORNL) produced a dataset that models the extent of storm surge under 0.5 m of SLR for the Gulf and Atlantic Coasts (Maloney and Preston 2014). The dataset uses storm surge from the Sea, Lake and Overland Surges from Hurricanes model (SLOSH) from the National Hurricane Center (NHC) of NOAA and adjusted the model to extend an additional 0.5 m. The extent is shown in Figure 32.

The 0.5 m SLR is the lowest SLR scenario of this assessment. Even under the low-end SLR scenario, there is a 10% increase in area affected by a Category 3 hurricane (Saffir-Simpson Hurricane Wind Scale). Storm surge from a Category 3 hurricane submerges all barrier islands, and the majority of Aransas County including the Rockport/Fulton area.

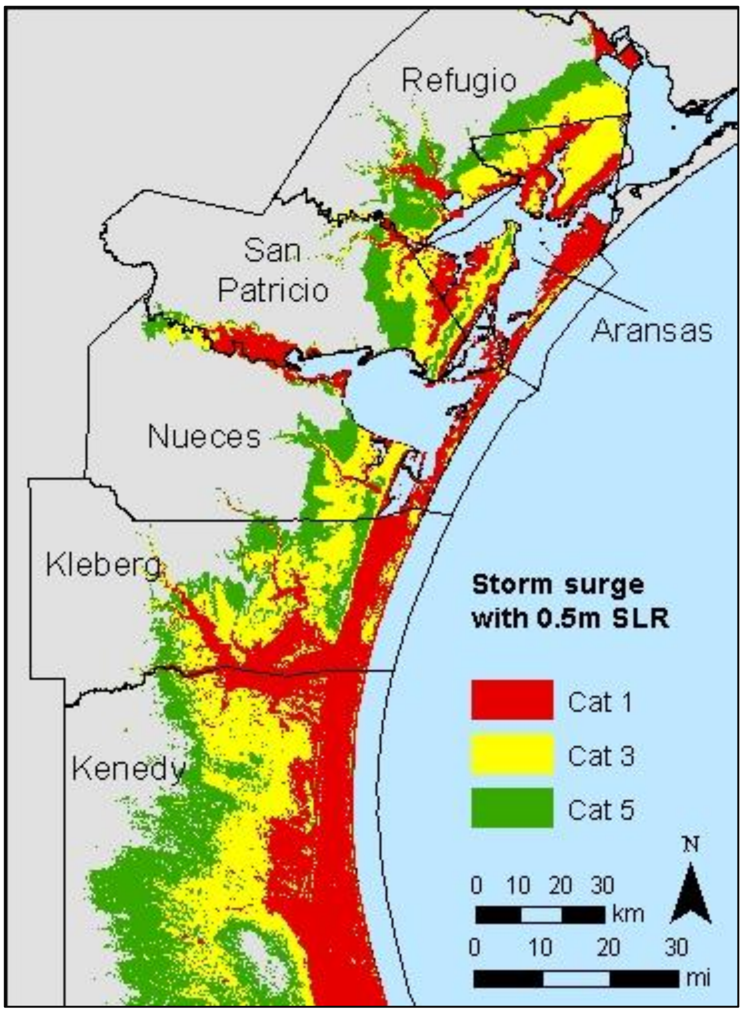

Figure 32. Storm surge in Coastal Bend counties of Texas. Storm surge was modeled using SLOSH model (NOAA) and 0.5 m SLR. Cat=Category of hurricane classified using the Saffir-Simpson Index. Data obtained from Maloney and Preston 2014.

The storm surge analysis conducted by Brenner and Thompson (2013) shows that human communities throughout the Corpus Christi Bay region face risks to SLR and storm surge, and that storm surge impacts from "today's" hurricane will be substantially amplified by climate-enhanced SLR and storm surge in the future. It also indicates marshes provide a valuable ecosystem service by protecting the coast against storm damages attenuation of storm surge and waves. Conversely, the absence of salt marshes can amplify the impacts of storm surge and increase the damages potentially suffered in future storm events. In this study the 2050 and 2100 storm-surge scenarios, which include 1 m of SLR by 2100, are predicted to inundate an estimated 84,988 and 106,505 acres, respectively. This constitutes an increase of over 42% percent from the 2006 baseline scenario through 2100, indicating that 1 m of SLR can increase near term storm-surge exposure by a considerable factor. In addition to the storm surge models that include all the SLAMM land cover categories, another model was run for the year 2006 using the same category 1 hurricane simulation that had the entire salt marsh habitat removed. This analysis was conducted to determine the attenuation effects that marshes have on storm surge and how they play a role in coastal protection and community resilience. The results of this analysis indicate that without marshes the potential impacts of storm surge would increase within the study area covering 75, 831 acres, or an additional 951 acres of land inundated in the no marsh scenario.

Wildlife and Ecosystems

Habitats

The fate of coastal habitats is strongly dependent on climate change variables and anthropogenic stressors. As sea level rises, a specific habitat may be able to persist if it migrates landward. This "keep up" strategy is only feasible if there is a) undeveloped land for the habitat to shift to, and b) the land is conducive for that type of habitat. A habitat may not be able to shift if there is human development blocking migration or if the physical environmental variables do not meet a certain species needs.

The increase in frequency of extreme weather events (heat stress, hurricanes, floods, wildfire) may lead to a loss of a habitat because species do not have enough time to recover between traumatic events (Lirman 2003). Moreover, the shift to warmer temperatures may decrease the viability of species by disrupting their growing cycle.

<u>Coastal wetlands</u>

SLAMM enables projections of marsh movement and viability under a variety of SLR scenarios. It uses the dominant processes involved in wetland conversion and shoreline change to project potential futures of coastal habitats. Some of the dominant processes are erosion/accretion (soil budget), subsidence, land slope and elevation, and saturation.

Warren Pinnacle Consulting conducted a Gulf-wide SLAMM at 15 m resolution (Warren Pinnacle Consulting 2015). This data

[30] http://sealevel.climatecentral.org/ssrf/texas

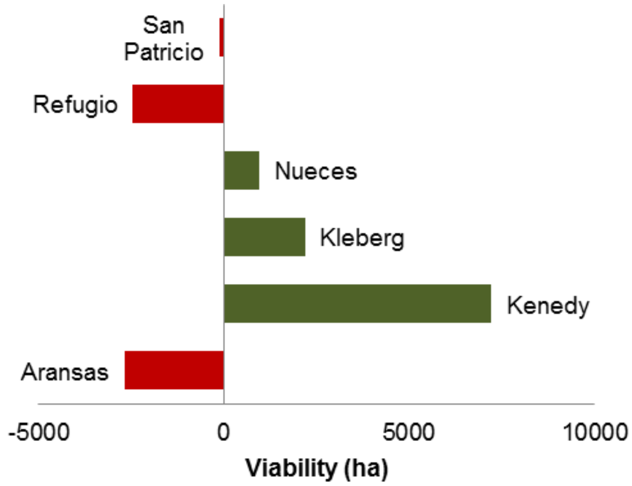

Figure 33. Marsh viability under 2.0 m SLR by 2100. Positive numbers indicate an overall growth in marsh area while negative numbers indicate net loss of marsh area.

was used to analyze marsh viability under the high scenario (2.0 m SLR by 2100). Marsh viability was analyzed at the county level and is defined with the following equation (Thompson et al. 2014):

Marsh viability = (marsh advancement + marsh persistence) – marsh loss

Aransas and Refugio counties have the lowest marsh viability in the Coastal Bend area with an overall net loss of marsh (Figure 33). Kenedy County has the highest marsh viability in the study area. This is mainly due to the fact that little marsh habitat currently exists in this area so there is not much marsh to be lost. On the other hand, this area is also highly unpopulated so that marsh habitats have the opportunity to migrate landward. Most marsh gain in this area is on the barrier island which is undeveloped and a federally protected area (Padre Island National Seashore; Figure 34).

For the entire Coastal Bend area, under the intermediate level scenario there is only an increase in transitional marsh and ocean beach. Transitional marsh marks the zone where the salt marsh shifts to upland habitats. Under the high SLR scenario, this habitat is also increasing.

In regards to other climate change stressors, coastal wetlands will also change community composition. As air temperatures increase and the chance of frost decreases, frost-intolerant species, such as mangroves, will be able to become established in more areas. Black mangroves (*Avicennia germinans*) have expanded their range in Texas due to warming winter temperatures (McKee et al. 2012). Osland et al. (2013) predict that under the high and low scenario, mangrove distribution will increase to all tidal wetlands in the Coastal Bend region and the high scenario will yield a mangrove-dominant community.

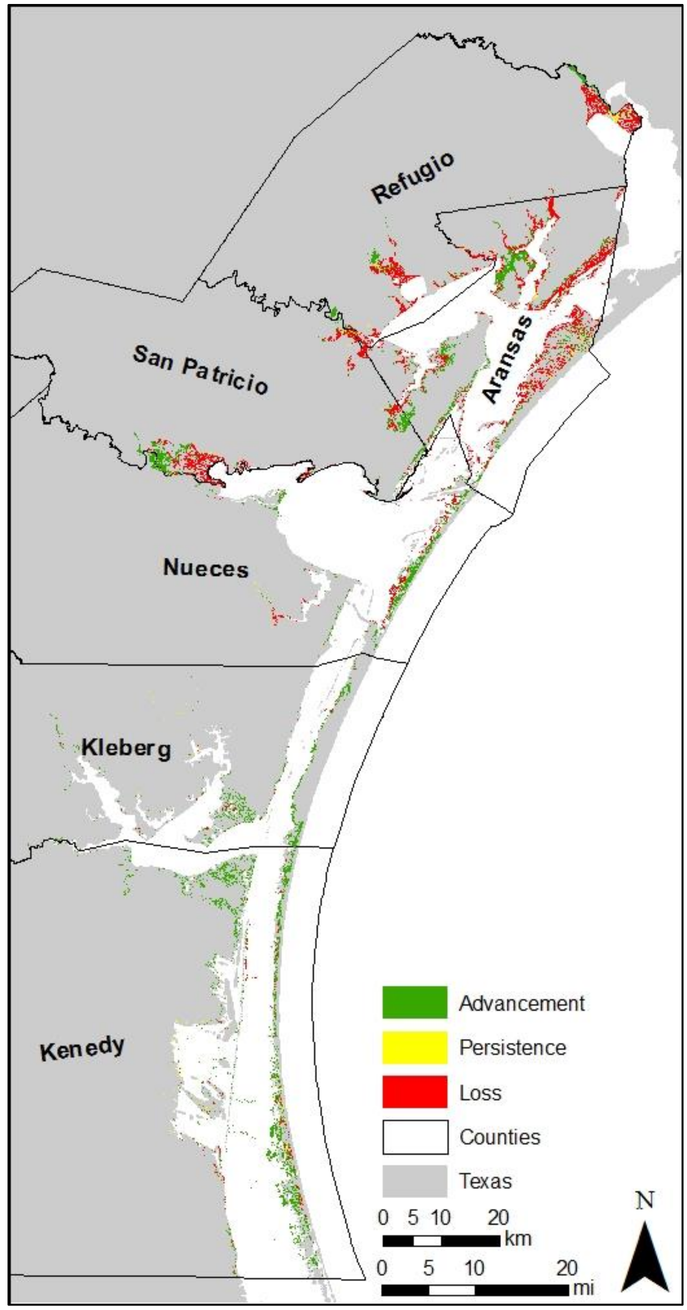

Figure 34. Areas of marsh advancement (gain), persistence, and loss predicted by SLAMM under 2.0 m of SLR by 2100.

Seagrasses

Seagrass communities are sensitive to changes in water parameters. In fact, they are often dubbed "coastal canaries" as they typically are the first species in an estuary to be impacted by change in environmental conditions. Changes in water temperature and water chemistry are likely to decrease the physiological efficiency of seagrasses, thus decreasing their viability. SLR threatens current seagrass extent as light attenuates with depth and seagrasses require light to survive[31].

The dominant seagrass in the Coastal Bend area is *Halodule wrightii* (Shoalgrass; Wilson & Dunton 2015). *H.wrightii* is able to live in a wide range of salinities and temperatures, and is an

[31] http://texasseagrass.org/

opportunistic colonizing species (often the first to become established after a disturbance). Due to these qualities, this species may be able to adapt and thrive in an uncertain future.

It is critical to maintain seagrass communities as they play many roles in the coastal environment. They provide nursery habitat for recreationally and commercially important species, they release oxygen into the water during photosynthesis which is the same process that also makes them carbon sinks, and they stabilize coastal sediments contributing to better water quality.

Wildlife

Changes in the underlying habitat on which species depend, will ultimately change the distribution, survival, and community structure of species.

<u>Marine species</u>

Changes in hydrology will likely have a large impact on marine fauna. Reduced freshwater inflows will increase the salinity of coastal waters. Some species are adapted to particular salinities and may be threatened by prolonged exposure to higher salinities. Salinity also acts as a barrier for some species. By changing salinity regimes, diseases, predators, and other competitors may be able to spread to areas that were once not suitable, threatening native wildlife. For example, the oyster fishery in Apalachicola Bay crashed in 2012 likely due to low river flows from the Apalachicola River causing the bay to become more saline. During 2012, several studies noted the abundance of oyster predators, as well as oyster shell parasites, that were typically not found in the lower salinities that the bay normally exhibits (Camp et al. 2015; Havens et al. 2013).

In addition to freshwater inflows, ocean acidification will also make it more difficult for oysters and other calcifying organisms to thrive. Even organisms that are not calcareous may be impacted by ocean acidification. It is still unclear, but ocean acidification is likely to cause physiological impacts to fish as they have to spend more energy regulating the balance of pH internally. It may also affect growth and development of larvae, which ultimately impacts survivorship (Baumann et al. 2012). Decreased fish stocks would have a serious impact to the Coastal Bend region as a high proportion of livelihoods are reliant on tourism, which a large proportion includes recreational fishing.

<u>Birds</u>

The distribution of many birds is associated with winter and summer temperatures. Increasing temperatures may expand species ranges, as well as, shrink others. Temperature changes are likely to change the timing of reproduction, migration, and growth of species, ultimately affecting survival.

Increased extreme weather events could decimate habitat and/or decrease food supply for bird species. Every year millions of birds migrate across the Gulf of Mexico to reach their winter or summer habitats. The Texas Coast is the first landing area a bird may have encountered in 1000 km. As sea level rises, this landing refuge will become further away and less of it will be available. Maintaining coastal habitats for bird refuge during this trans-gulf migration is critical to bird survival.

Rookery Island data from 2008[32] shows that there are over 250 rookery islands in the Coastal Bend area, ranging in size from 2.5 m^2 to 455 ha (4,555,410 m^2; La Quinta Island). Based on the intermediate SLR scenario, 135 islands will be submerged by 2100 or almost half (47%) of the rookery islands currently present in the area. This is a loss of 308 ha of habitat just by rising sea levels. Erosional forces from increased wave action and storm severity will further decrease the area of habitat available if no action is taken to protect these islands. These compounding factors will lead to a decrease in safe areas for bird species to nest, away from predators.

Audubon compiled species distribution data and modeled how bird habitats and ranges may shift under climate change[33]. They constructed “range” maps for 588 bird species to aid in the prioritization of conservation areas. The report identified that 314 species of North American birds (out of 588 species) will lose 50% of their current range by 2080 if global warming continues (National Audubon Society 2014).

<u>Invasive Species</u>

As stated previously, as climate changes species distributions can shift. Increasing air and water temperatures may remove environmental constraints on some tropical or sub-tropical species, allowing them to become established in the Coastal Bend area. This could lead to native species displacement, altering the ecology, economy, and community of the Coastal Bend area. The Coastal Bend is at higher risk of marine invasive species due to the Coastal Bend having one of the largest Ports in the nation. The ship traffic could inadvertently bring non-native species to the area, through fouling or transfer of ballast water.

[32] http://maps.coastalresilience.org/gulfmex/

[33] http://climate.audubon.org/

Coastal Bend Climate Change Vulnerability and Resiliency Workshop

The assessment of the vulnerabilities in the Texas Coastal Bend region would not be completed without the input of local communities on actions to reduce their vulnerability and opportunities to enhance adaptation to stressors. On December 15, 2015 the CBBEP and TNC conducted the "Coastal Bend Climate Change Vulnerability and Resilience Workshop" at the Mission-Aransas National Estuarine Research Reserve (MANERR) in Port Aransas, Texas. Since the intent of this project aligns with the EPA's Climate Ready Estuaries Program initiative to assess climate change vulnerabilities, develop adaptation strategies, and engage and educate stakeholders, the goals of the workshop focused on: 1) disseminating the coastal resilience approach and methods used in the coastal vulnerability assessment, and 2) gathering the input of participants about strategies for adapting to climate related coastal hazards and building resilience.

During this half–day workshop, the project team presented to and discussed with the local stakeholders of the Texas Coastal Bend their ideas and concerns to overcome the risks and build resilient communities along the coast. The workshop had 26 participants representing counties and cities (27%), state and federal agencies (42.3%), academia (7.7%), and non-for-profits and firms (23%). Presentations of the workshop included: introduction to The Nature Conservancy model of coastal resilience and the coastal vulnerability assessment, vulnerability assessment in the Mission-Aransas Estuary, review of the SLAMM-based sea-level rise scenarios for Copano and San Antonio bays, and tidal datums and stillwater level flooding frequencies at the Bob Hall Pier, Texas. The complete agenda, list of participants and presentations can be obtained and downloaded from the workshop webpage: http://missionaransas.org/coastal-bend-vulnerability-and-resiliency-workshop-0.

After the presentations and answering the questions of the audience, the group discussed their concerns about the climate-related risks for their communities, natural resources and infrastructure, and ideas about how to become more resilient by reducing their vulnerabilities. These aspects have been integrated into the following topics:

Aspects that reduce vulnerability and support adaptation:

- Work on educating people in Texas to change their perception (resistance and reactions) to the climate change word and issues. The ultimate goal is to be resilient and therefore the Coastal Resilience Index could help identify the initial issues and concerns along communities.
- County-level plans tied in with local emergency managers are needed in 2017.
- Protect critical facilities along the entire coastal zone and build new facilities away from floodplains.
- Factor in local to regional subsidence as it is a huge issue along Texas coast.
- Identify the areas where marsh habitat will be able to migrate due to sea-level rise and where marsh conservation is needed to reduce community vulnerability. Also identify areas of concern where vulnerability could increase due to marsh loss.
- Protect sand dunes – e.g., Kleberg County. Factor in Erosion Response Plan, dune permitting plan, and focus on beach profile. Setbacks are not straight lines; they change because of the need to avoid critical dunes that migrate inland and other important features.
- Conduct better and more frequent surveys to assess the changes in barrier islands. Due to the high concentration of people and activities on these features, having surveys more frequent than every five years (as the Texas General Land Office does currently) would be beneficial for plans and to take action. Unmanned aerial vehicle technology may make this more affordable, perhaps annually.

Big gaps in building resilience:

- Allow planners, managers and the public access to more complex models that integrate sea-level rise, storm surge, temperature and precipitation stress, and urban growth to enhance our predictive capacity and understand coastal complex processes and their impacts in communities (e.g., Advanced Circulation Model and CHARM Model).
- Identify realistic scenarios for the Texas coast that support focused planning efforts and resources for adaptation. Potentially develop 'near term' scenarios e.g., 2050 to focus planning efforts.
- Add economics to this type of assessment to grab peoples and 'decision-makers' attention. Education component and economic impact needed – package these aspects together and it is a huge opportunity.
  Make more data, tools, scenarios and assessments freely available to planners, academia, and decision-makers – e.g., use http://www.coastalresilience.org to support mitigation projects and guide when sea-level rise needs to be a factor – think about impacts of changing coastal prairie to marsh

Future aspects:

- Conduct a follow up survey to identify needs moving forward as there are lots of great plans in the region, but local government uses FEMA plans, so Hazard Mitigation Plans are key for hazard mitigation.

Summary & Recommendations

Summary

In this section we provide a summary of the main vulnerabilities of the sectors assessed in the Coastal Bend area in Texas.

- Critical facilities. Although the risk of inundation for most fire stations and health care facilities is low under the intermediate and highest SLR scenarios, a number of these facilities are still within 100 m to 1000 m of the 1.2 m inundation scenario (intermediate). This proximity aspect makes them vulnerable by potentially compromising the efficiency of their operations. For example, the Port Aransas Wastewater Treatment Plan is at risk under the intermediate scenario and all other plants are only 300 m from the maximum inundation line of that same scenario. Although the main roads or airports are not expected to flood, it is important to consider that the future traffic to “safe” transportation infrastructure will be compromised.

- Economic activities. An increase in economic activity is expected, driven by continuous population growth in coastal areas. This growth also puts this area in more risk to climate-related damages and loss of economic activity. Based on the size of their economies, the industries identified as vulnerable are oil and gas, mining, construction, accommodation and food services, retail trade, and health care. All counties rely on the oil and gas industry for employment and coincidently it is the one that is most at risk due to SLR and storm-related impacts because infrastructure could become inoperable and the means of supply and distribution disrupted. Secondly, the Coastal Bend area is largely an agricultural economy. Agriculture is expected to be heavily impacted by weather patterns and climatic conditions that depending on the scenario chosen the associated yield projection changes drastically (e.g., some models suggest that some crop yields could be better under a high scenario). Additionally, the production costs may increase as water availability is reduced. Coastal tourism may also experience some economic fluctuations as the weather patterns change and becomes less stable and potentially some habitats are degraded due to the combination of several stressors (e.g., SLR). Although construction is likely to continue growing from the influx of population in the coastal areas, as a weather-dependent industry and it will also impacted by disrupted weather patterns.

- Cultural resources. Three places in the National Register of Historic Places could be vulnerable due to their proximity to the bays in the intermediate SLR scenario (~100 m). The only lighthouse in the study area, the Lydia Ann Lighthouse, is now vulnerable to Category 1 hurricanes and to future SLR.

- Human health. Future higher temperatures will increase the direct stress in the population by increasing the risk of heat-related illness. Although some sectors of the population are more vulnerable (based on age, health status, income), these aspects of stress are preventable by continuing to inform them of precautions while conducting labor or recreational outdoor activities. The expected increase in coastal population, changes in precipitation patterns, increase of evaporation, and salt water intrusion or invasion due to SLR, will contribute to the potential decrease in available freshwater supply. Therefore the population would become more vulnerable due to the limited supply for consumption and the deterioration of water quality (due to increased temperatures and reduction of dissolved oxygen) to maintain adequate health levels in the population. Human health could be compromised in certain areas by changes in air quality such as a longer plant growing season that promotes allergens and the potential increase of pollutants such as ozone due to greater amounts of sun light and increased air temperatures.

- Water resources. As the majority of the Coastal Bend Regional Water Plan area relies on surface water, increases in air and water temperature that increase evaporation rates and compromise water quality will reduce the surface water supplies. There are several communities and user groups in the Coastal Bend water planning region (Region N) that are largely depend upon groundwater resources. While the CBRWPG & GCDs promote the efficiency in the use of the groundwater resources, including preventing land subsidence which contributes to the impacts of SLR, it does not incorporate management actions to cope to climate change stressors such as saltwater intrusion of groundwater resources.

- Coastal resources. Around 30% of Texas shorelines have high erosion rates (over 1 m per year). Shorelines are eroding at an average rate of 0.70 m per year with some locations losing up to 9 m per year. The communities at higher risk to erosional forces are North Padre Island and Flour Bluff. SLR is partially responsible for the erosion suffered but also poor management is also a relevant factor as coast bulk heading, jetties and other structures have replaced natural habitats that used to border and protect the shoreline. SLR will also expand the area subject to inundation due to storm surge, increasing the odds of damaging floods. Under the intermediate SLR scenario, a 100-year flood will become 20% more likely to happen by 2030 in Rockport and by 2080, the likelihood increases to 100%. Similarly under the low-end SLR scenario, there is a 10% increase in area affected by a Category 3 hurricane. This storm would submerge all barrier islands, and the majority of Aransas County including the Rockport/Fulton area.

- Wildlife and ecosystems. Many climate change factors contribute to the degradation of habitats and wildlife of the Coastal Bend area. If sea level rise happens at a high rate, plant communities may not be able to re-establish landward and essentially drown. Additionally, if landward migration is not an option due to human development, these ecosystems will get squeezed out. Due to the dependency of species on the coastal habitats, land conservation and promotion of healthy waterways should be focused on to promote retention of biodiversity.

Recommendations

Understanding how the impact of one stressor will impact other sectors constitutes a difficult task as complex natural and economic processes rule the interactions between both systems. This assessment constitutes a first attempt to identify the key vulnerabilities of the Coastal Bend area and the opportunities for reducing them and adapting to a changing environment. The following recommendations constitute an attempt to integrate multiple views needed in the process of building a resilient Coastal Bend area.

- Facilitate and support studies to better understand local biological, chemical, and physical effects of climate change. Bridge the gap between the climate science and the planning, management and decision-making communities by identifying the key information aspects needed to build resilience in each of them. For example – translate key science-based vulnerabilities into easy to understand components of people's well-being and express them in monetary terms.

- Increase community resilience to most drastic hazards, such as storms, by building in redundancies (alternative or primary) in power generation that are based on natural gas, a more reliable energy source after storm rebuilding. Communities should adopt an early flood warning system and coordinate other adaptation measures through their planning and emergency departments to maximize public response to adaptation needs through education. Communities should look into creating incentives for the acquisition of repetitive loss properties. When possible retrofit infrastructure with energy efficient facilities.

- Build coastal resilience by restoring coastal habitats that protect communities and infrastructure. Coastal vegetation habitats, such as salt and freshwater marshes, should be allowed to migrate landwards together with SLR to minimize losses and maintain resiliency. Invest in a combination of grey and green infrastructure that builds resilient communities and take into account the social benefits and costs.

- Assist local governments in developing and implementing adaptive management plans that conserve and protect the Coastal Bend area's ecological services. Address climate adaptation, and the threats of SLR and storm surge in the Comprehensive Plans of the communities in the Coastal Bend area. For example - adjust plans and policies to require that new construction occur outside the flood areas and include these changes in the City's facilities plan. Involve all supporting industries such as utility providers in the planning process.

- Develop and implement educational programs and distribute literature about the effects of climate change. Education programs should cover a diverse group of topics from human health to storm preparedness to protection of natural infrastructure, among others.

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