Gulf Coast Community Handbook

Case Studies from Gulf of Mexico Communities for Incorporating Climate Change Resiliency into Habitat Planning and Protection

A report to the US Environmental Protection Agency, Climate Ready Estuaries Program

Developed by Lindsay M. Cross, Tampa Bay Estuary Program

January 2014

Table of Contents

Foreword and Acknowledgements 1

Introduction 2

Scientists Worldwide Researching Climate Change 3

Overview of Climate Change Science 4-5

- Sea Level Rise 6
- Storm Impacts and Extreme Weather 7
- Changes in Precipitation and Temperature 8
- Impacts to Flora and Fauna 9
- Ocean Acidification 10
- Additional Gulf of Mexico Impacts 11

Gulf of Mexico Case Studies and Activity Codes 12

National Estuary Programs 13

- Barataria-Terrebonne National Estuary Program, Louisiana 14-15
- Charlotte Harbor National Estuary Program, Florida 16-19
- Coastal Bend Bays & Estuaries Program, Texas 20-21
- Partners of the Galveston Bay National Estuary Program, Texas 22-24
- Mobile Bay National Estuary Program, Alabama 25
- Sarasota Bay Estuary Program, Florida 26-29
- Tampa Bay Estuary Program, Florida 29-33

National Estuarine Research Reserves 34

- Addressing Reserve Resiliency through Disaster Response Planning 35
- Sentinel Sites Monitoring Program Will Detect Climate Change Impacts at NERRs 36-37
- Apalachicola National Estuarine Research Reserve, Florida 38-39
- Grand Bay National Estuarine Research Reserve, Mississippi 38, 40, 46-47
- Mission-Aransas National Estuarine Research Reserve, Texas 35, 41
- Rookery Bay National Estuarine Research Reserve, Florida 42-44
- Weeks Bay National Estuarine Research Reserve, Alabama 38, 40, 45-47

Step-by-Step Recommendations 48-49

Recommended Readings 50

Document should be referenced as:

Cross, L.M., 2014. Gulf Coast Community Handbook: Case Studies from Gulf of Mexico Communities for Incorporating Climate Change Resiliency into Habitat Planning and Protection. Report to the US Environmental Protection Agency. Technical report #01-14 of the Tampa Bay Estuary Program, St. Petersburg, FL.

Available at: www.tbeptech.org/DATA/cre/gulfcoasthandbook.pdf

Foreword and Acknowledgements

Climate change will affect what we need to do in order to protect human health and the environment. Being ready for climate change means taking actions to reduce the risks that would keep us from achieving our goals.

The National Estuary Program and National Estuarine Research Reserve System cases described in this handbook will inspire others. The accounts from cities, parks, and bays around the Gulf of Mexico show that preparing for climate impacts can take many forms. These examples demonstrate that asking climate questions leads to decisions and robust projects that will continue to provide benefits for decades to come—even as the sea rises and the climate changes.

The case studies and resources in this handbook will help any organization facing the challenge of identifying, analyzing and evaluating risks. Examples of what others have done to prepare show that climate change risks can be addressed and places can get climate ready.

Michael Craghan
Program Manager,
Climate Ready Estuaries Program

US Environmental Protection Agency,
Oceans and Coastal Protection Division
Washington, D.C.

craghan.michael@epa.gov

CLIMATE READY ESTUARIES
EPA

Acknowledgements:

Thank you to the many scientists, managers, and outreach specialists who provided reports, text, photos, and graphics for this handbook. The source of all graphics not produced by the Tampa Bay Estuary Program is noted. Persons listed as contacts for individual projects provided written summaries and graphics for those respective pages, as well as editing support. I appreciate the input of staff from the Gulf Coast National Estuary Programs and National Estuarine Research Reserves, as well as their project partners. Additional content and editing was provided by Holly Greening and Nanette O'Hara, Tampa Bay Estuary Program; Libby Carnahan, Florida Sea Grant; and Vicki Parsons, Bay Soundings. Finally, thank you to the US Environmental Protection Agency for funding support and for initiating this important and timely project through the Climate Ready Estuaries Program.

Lindsay M. Cross
Environmental Science and Policy Manager
Tampa Bay Estuary Program
St. Petersburg, FL

lcross@tbep.org

TAMPA BAY Estuary Program

Introduction

Climate change has the potential to affect humans and the environment in significant ways. Some of the predicted effects include sea level rise, changes in temperature and precipitation, and increased intensity of storms and storm surge. Some impacts of climate change such as rising sea levels and changes in temperature and precipitation may already be observed in some areas.

Photo:climate-change-guide.com

These stressors can impact other life-sustaining processes, changing the rate and delivery of freshwater, altering the intensity or duration of extreme weather events, or causing erosion to coastal and inland habitats. Coastal communities may be especially vulnerable to predicted, as well as unforeseen, impacts from climate change. In order to ensure the survival and robustness of these areas, including the natural environment, it is prudent that coastal communities begin evaluating their potential risks, developing management options, and implementing workable solutions.

This handbook provides a review of the current knowledge of climate change science, as well as concrete examples of what communities around the Gulf of Mexico are doing now to improve the resiliency of habitats in the face of a changing climate.

Handbook focuses on natural resources

While many of the activities discussed in this document may result in benefits for the built environment or community livability, the focus is on natural habitats and how Gulf coast communities can help ensure the survival and success of habitats and the species they support. Natural areas provide numerous ecosystem services, such as water filtration, shoreline protection, and carbon storage, as well as having intrinsic and recreational value. This document illustrates how climate change aspects can be incorporated into habitat projects in order to enhance their long-term resiliency and the benefits they provide.

Charlotte Harbor, FL salt marsh. Photo: CHENP

Communities encouraged to begin climate change dialogues

If left unmanaged, climate change may cause undesirable impacts, but it may also serve as a catalyst to bring community members together to begin talking about climate change in a constructive manner. Readers are encouraged to contact the agencies highlighted in this handbook to further discuss how their experiences may benefit your community and to share this document with others, as a way to initiative productive conversations and to develop collaborative solutions.

Photo: Sara Heaton

Funding for this document was provided by the US Environmental Protection Agency's Climate Ready Estuaries (CRE) Program. For more information on other CRE initiatives, please visit: www.epa.gov/cre

CLIMATE READY ESTUARIES

EPA

Scientists Worldwide Researching Climate Change

Climate data is being collected and compiled by numerous entities worldwide

Climate scientists and managers are constantly updating information related to climate change, its contributing factors, and its potential impacts to a wide array of regions and sectors. There are numerous excellent publications that provide an in-depth look at climate science and what impacts may be expected to people, infrastructure, and the environment. It is recommended that readers refer to the original documents, however, a review of several recent publications is provided within this handbook. Links to the original publications are also included in the Recommended Readings section.

National Climate Assessment

globalchange.gov
U.S. Global Change Research Program

On a national level, the Global Change Research Act of 1990 mandates that a national climate assessment be conducted every four years, resulting in a report to the President and Congress. The Draft Third National Climate Assessment (NCA) was published in 2013 and is available at http://ncadac.globalchange.gov. This extensive report documents how climate change may impact regions across the US and nearly 20 sectors, including water resources, forestry, ecosystems and biodiversity, land use and land cover change, biogeochemical cycles, and oceans and marine resources.

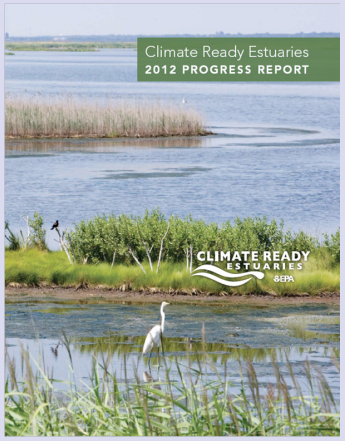
Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). It brings together thousands of the world's top scientists, economists, and other experts from 195 countries to synthesize peer-reviewed scientific and socio-economic literature on climate change. The IPCC produces assessments of the current state of knowledge of climate change and its potential environmental and socio-economic impacts. A Summary for Policymakers and a final draft of the Physical Science Basis of the Fifth Assessment Report was published in Fall 2013 with subsequent chapters in 2014. Up-to-date information can be found at http://www.ipcc.ch/index.htm

Restore America's Estuaries published "*Restore-Adapt-Mitigate*" - a resource for agencies involved with habitat restoration. It includes multi-scenario approaches to planning and ways to prioritize restoration activities by planning for different projections of climate change. Available at: http://www.estuaries.org/images/stories/RAE_Restore-Adapt-Mitigate_Climate-Chg-Report.pdf

Visit: http://www.estuaries.org/ for more information on the nation's network of estuaries.

The US Environmental Protection Agency, through its *Climate Ready Estuaries* program, publishes annual progress reports and special studies from estuaries around the country, a coastal toolkit, and a new workbook for developing risk-based adaptation plans. Visit: http://water.epa.gov/type/oceb/cre/index.cfm



Overview of Climate Change Science

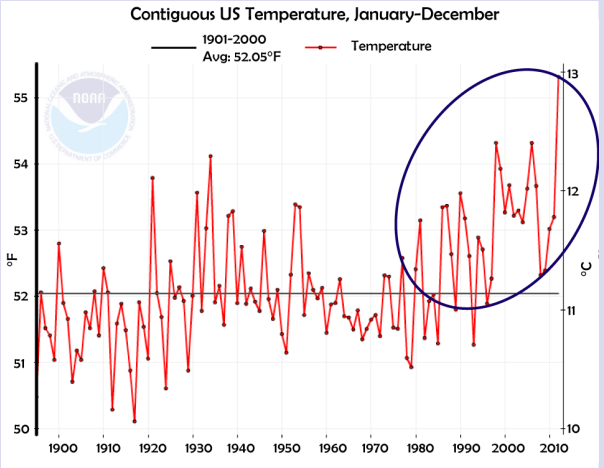
Earth's climate has always been changing

The Earth's climate has been changing throughout geologic history, experiencing both warmer and cooler periods. During the most recent ice age, which began 2.5 million years ago, large parts of North America and Europe were covered with giant ice sheets. When the Earth's climate warmed, these ice sheets retreated, leaving physical imprints such as the Great Lakes in the northern US. Throughout geologic time, the level of the seas and the coastlines of the continents also changed. During some periods, the extent of the coastlines was larger; at other times current land masses were under water.

North America's coastline and ice sheets (shown in white) during the peak of the last glacial cycle. The yellow outline shows the modern coastline drawn over the historic landmass, which is shown in green. Source: adapted from www.dmns.org

Climate now changing at a faster rate

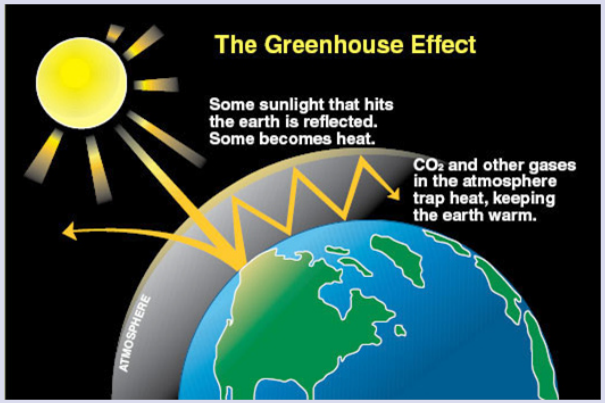
Temperatures on Earth generally change gradually, taking tens of thousands of years to transition from glacial to warmer periods. Since the last glacial period ended 10,000 years ago the Earth has been experiencing a warming period. Starting about 200 years ago, the Earth was in a brief cooling period known as a Little Ice Age. However, during the last century, global temperatures have been rising and this warming trend is continuing at a higher rate than previously measured.



The graph above shows average annual temperatures in the contiguous US between 1900 and 2013. In the early part of the 20th century, average annual temperatures were lower than the 100-year average, although there was a general warming trend. Towards the mid-century, average annual temperatures were generally higher than the 100-year average, with larger increases seen in recent decades, shown in the blue oval for emphasis. Source: adapted from NOAA, National Climate Data Center

Greenhouse gases contributing to warming

A contributing factor to higher global temperatures is the Greenhouse Effect. This occurs when greenhouse gases like carbon dioxide (CO_2) are released from human activities such as the burning of fossil fuels. These gases trap heat from the sun, keeping the Earth's surface warm enough for humans and plant and animal species to survive. However, increasing amounts of these greenhouse gases in the atmosphere trap additional heat, leading to a warming of the air, land, and waterbodies. It is possible that the warming associated with increased greenhouse gases may override the natural climate cycle. While some areas may experience cooler temperatures, the global averages are trending towards warmer temperatures and these trends are expected to continue and likely increase.

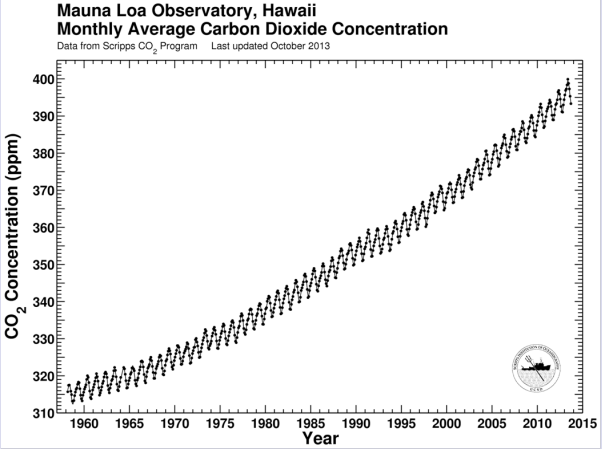


Increasing concentrations of greenhouse gases in the atmosphere can lead to warming of the Earth's land, water and air. Source: Washington State Dept of Biology

Long-term monitoring stations measure increasing concentrations of CO_2

Greenhouse gases can be measured by their concentration in parts per million (ppm) within the atmosphere. A long-term monitoring and observation system was established in Mauna Loa, Hawaii in 1960 and has been continuously measuring CO_2 concentrations in the atmosphere since 1960. Data show that the concentration of CO_2 in the atmosphere has been steadily increasing each decade since the 1960s, with a persistent year-to-year increase. There was a 35% greater concentration of CO_2 in the atmosphere recorded since the Industrial Revolution and a rise of 6% in the last 19 years alone.

Observations made by other programs and at other locations have found similar results to those measured at Mauna Loa.



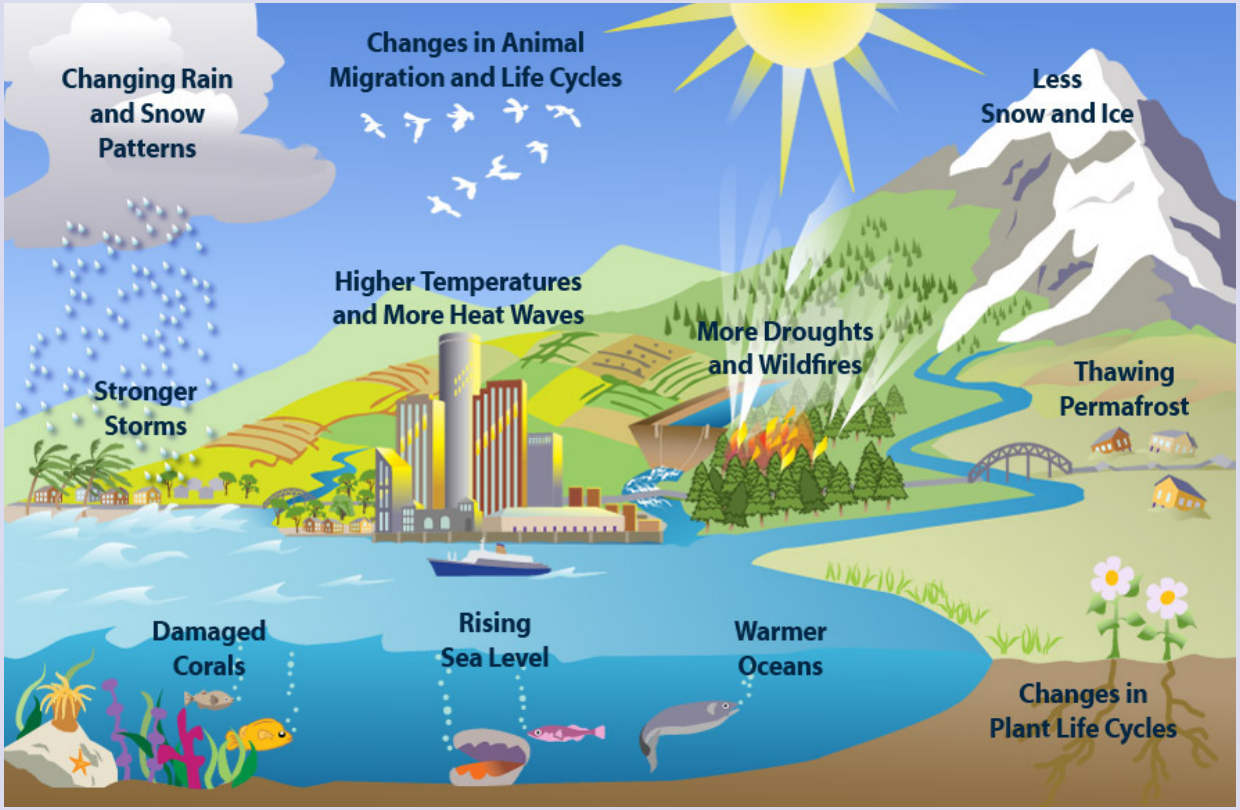
Data collected at Mauna Loa Observatory in Hawaii documents steadily increasing concentrations in CO_2 concentrations since 1960, as measured by monthly average CO_2 concentrations (in ppm). Source: Scripps Institute of Oceanography

Numerous climate change impacts predicted

Scientists predict that there will be numerous impacts to humans, the environment, and infrastructure as a result of climate change. These impacts will be explored in greater detail in the following pages, however, the graphic below depicts some of the predicted impacts, including:

- Changes in weather patterns such as higher temperatures, more heat waves, and changes in precipitation patterns;
- More extreme weather events such as droughts, wildfires, and stronger storms;
- Impacts to plant and animal species such as changes in animal migration and life cycles, changes in plant cycles and growing regions, and damage to coral reefs;
- Reduction in snow and ice cover and thawing of permafrost;
- Warming ocean temperatures; and
- Rising sea levels.

Many of these impacts will also act synergistically, causing greater impacts to the natural environment collectively than individually.



Predicted impacts of climate change are shown in the graphic above. Source: US Environmental Protection Agency

Sea Level Rise

Sea level rise is not a new phenomenon

Just as Earth's climate has been changing throughout geologic time, so has the height of the oceans, causing subsequent changes in extent of exposed land masses. While this is not a new phenomenon, global sea level rise (SLR) has been observed at a higher rate in recent decades and is expected to continue at a similarly high or even greater rate.

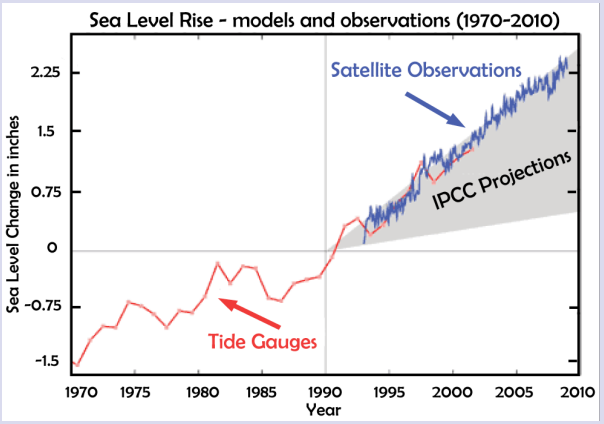
Warming and expansion of ocean waters create rising seas

Global sea level rise is caused by several factors, including expansion of ocean waters due to warming and loss of ice sheets and glaciers. Warmer water takes up more space than ice, so as ocean waters warm and ice sheets melt, a larger mass of water results, which is observed as a higher level of the sea.

The phenomenon of sea level rise is analogous to filling a bathtub with a larger volume than it can hold. As the tub becomes full, it overflows. With Earth's oceans, the additional volume of water encroaches on land masses as sea level rise. Photo: thisnessofathat.blogspot.com

Sea level rise measured from tide gauges and satellite observations

Scientists have already observed rising sea levels using measurements from tide gauges, as well as satellite observations. Overall, global sea level has risen 8 inches since 1880 according to recent reports. The relative sea level rise varies by location, depending on local characteristics such as subsidence.



Global sea level rise between 1970 and 2010 based on models and observations. Source: adapted from Allison et. al., The Copenhagen Discussions, 2009

Future scenarios rely on observations, models

Modeling future sea level rise can be difficult. While there are estimates available on a global scale, there are no widely accepted methods for transferring these projections to a more regional or local scale. Within some portions of the Gulf coast, relative sea level rise has been rising substantially faster (2-4 inches per decade) than the global trend (0.67 inches per decade).

Scientists have developed a range of global sea level rise scenarios. They vary based on the magnitude of expansion caused from warming waters and melting of ice sheets and glaciers. In 2012, the National Oceanic and Atmospheric Administration (NOAA) developed several sea level rise scenarios. NOAA scientists used 1992 as a starting point and projected scenarios out to the year 2100.

Scenario	Sea Level Rise by 2100
Highest	6.6 feet
Intermediate-High	3.9 feet
Intermediate-Low	1.6 feet

The lower scenarios assume no increase in sea level from ice sheet loss. Higher scenarios include a combination of ocean warming, as well as maximum ice sheet loss and melting of large glaciers, that would lead to a sea level rise of more than six feet by 2100.

Communities are encouraged to use different scenarios for different planning purposes. For example, higher scenarios should be used when there is less tolerance for risk, such as infrastructure with a long anticipated life cycle or for habitats that migrate very slowly, or not at all. Where greater risk is acceptable, a lower scenario may be more appropriate. These global scenarios are useful for planning purposes, but should be used in concert with variability at the local and regional level such as land subsidence or other factors.

Storm Impacts and Extreme Weather

It may be difficult for a community to envision how sea level rise will impact it and the habitats it values. However, it is likely that most communities have experienced periods of extreme weather or impacts from storms and associated storm surge. Southern regions, including the Gulf coast, have had the highest incidences of billion dollar weather and climatic disasters, according to the 2013 National Climate Assessment.

Sea level rise may increase intensity

Extreme weather events including hurricanes such as Katrina, Ivan, Rita, and Isaac cause significant damage to people, infrastructure, and the environment. They may cause irreparable harm to sensitive ecosystems resulting from changes in the hydrology or elevation of a system. Sea level rise will exacerbate the effects from extreme weather events, especially in areas that have not implemented adequate protection or adaptation measures.

Waves and storm surge destroy a pier along Mobile Bay, AL during Hurricane Isaac. Photo: Associated Press

Barrier islands may be especially vulnerable

Large storms or hurricanes may result in changes to transient features such as barrier islands. While these systems naturally shift position depending on wave impacts and sediment availability, the presence of infrastructure and hardened materials may artificially halt this movement. A major weather event, however, may breach an inlet or barrier island, creating new tidal channels or breaking the structure into smaller pieces.

New tidal channels cut through North Carolina's Outer Banks following Hurricane Irene. Photo: Tom Mackenzie

Barrier islands can help to protect mainshore coastal and upland areas by minimizing the impact of wave energy. Along with other natural areas such as marshes and mangroves, they are often the first line of defense against the damaging effects of wind and waves associated with storms and hurricanes. Coastal areas with healthy and abundant natural systems such as wetlands often fare better in storms than those without them.

Major flooding events more common

Even moderate precipitation events may cause flooding in areas and the occurrence of major events such as 100-year floods is becoming increasingly common. Extreme precipitation events have increased in most regions of the US, including the southeast and Gulf coasts. Flooding, especially repetitive events, puts stress on infrastructure such as drinking water supplies, as well as sensitive natural areas not accustomed to flooding.

Flooding along Bayshore Boulevard in Tampa Bay, FL following a high precipitation event. Source unknown.

Discussions about storm surge may open dialogue about climate change concerns

Extreme events highlight the vulnerability of our coastal areas. While destructive, they may help communities begin discussing resiliency, leading to the development of appropriate strategies for protecting their citizenry, infrastructure, and valued natural areas and species.

Changes in Precipitation and Temperature

While extreme weather events may inflict large damages and impacts to coastal areas, changes in the everyday weather patterns and climate may also stress local communities and environments.

Tomorrow's climate may differ from today's

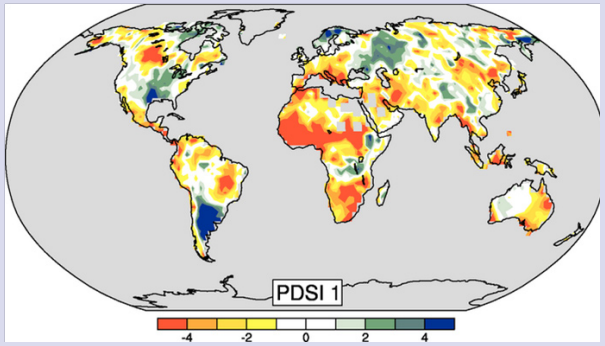
Over the last century, changes in average temperatures and precipitation have been observed. According to the 2013 DCA report, the US average temperature has increased by 1.5° F since 1895 with two-thirds of that gain since 1980. The number of extremely hot days is also increasing and the recent decade (2000s) was the warmest on record.

Rising temperatures and associated increases in frequency, intensity, and duration of extreme heat will affect human health, natural environments, agriculture, and forestry. Even small increases in temperature may trigger changes in life cycle, decreased resistance to disease or, in extreme cases, death in some species.

Climate change may bring hotter average temperatures. Photo: Irfan Khana

Warmer air temperatures will impact precipitation patterns and intensity

Precipitation, whether falling as rain or snow, first begins when water is evaporated into the atmosphere from Earth's surfaces. Air and water temperatures play a role in this as rising air temperatures can lead to an increase in evaporation from waterbodies and a drying of the land surface.



The graphic above measures drought using the Palmer Drought Severity Index (PDSI). Areas in green or blue (positive values) are expected to become wetter; areas in yellow or red (negative values) are expected to become drier. Source: IPCC

Scientists predict greater variability

While precipitation patterns vary from year-to-year, especially during periods such as El Niño or La Niña, climate change may lead to even more variability and less predictability in weather patterns. Scientists generally anticipate that higher air temperatures will result in heavier but less frequent precipitation events interspersed with periods of drought.

In the southern region of the US, summer drought periods are expected to intensify as water supplies shrink. This will lead to reduced runoff and soil moisture content. Decreasing water availability will lead to increased competition for water between municipal, agricultural, and environmental uses, which will be exacerbated by population growth and land use changes.

Droughts will negatively impact agricultural crops such as corn. Photo: Mashid Mohadijierin

Precipitation events, when they occur, will likely be more intense, potentially leading to flooding. Natural areas may be physically damaged. Heavy rain events and excess stormwater carrying nutrients and pollution may lead to water quality impairments in receiving waterbodies such as estuaries.

Photo: hungeree.com

Impacts to Flora and Fauna

Climate change will cause impacts to plant and animal species, some of which may be controlled, some that may not. It is important that coastal communities identify and implement the most appropriate adaptation strategies for valuable habitats and wildlife. Some anticipated impacts include:

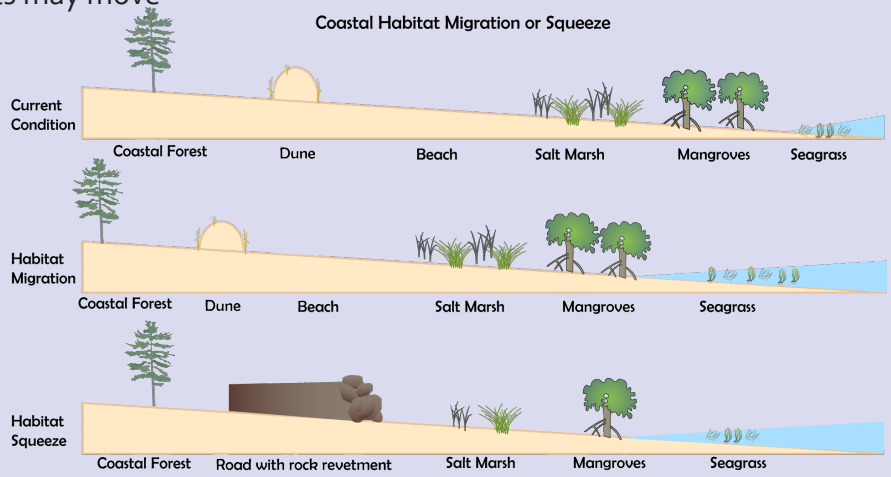
- Changes in the range and/or life cycle of some species,
- Compression of habitat ranges, and
- Encroachment or out-competing by non-native, invasive species.

Habitat ranges may compress without proper planning and adaptation measures

The natural range of a plant or animal species may shift due to changes in climate, such as warmer air or water temperatures. In southern portions of the Gulf Coast, for example, it is anticipated that the range of mangrove habitats may move northward into current salt marsh areas. While both estuarine wetland habitats exist in some areas, salt marsh plants tend to be more tolerant of cold temperatures. With an increase in air temperatures and a lack of winter freeze events, mangroves may encroach into salt marsh areas.

Changes in climate and sea level rise may force habitats to move to higher elevations or to areas with different climatic regimes. If there is sufficient available land upslope and if the climate doesn't change faster than the ability of the species to respond, plant and animal species may be able to migrate into other areas. In the same example, a mangrove forest may move into an area that was once occupied by salt marsh, which may then move into a beach area. However, if there are hardened features in place, such as roads or seawalls, the habitat may become squeezed off, ultimately leading to losses in important habitat types that support valuable fish and wildlife species. This underlies the importance of protecting not only current habitat areas, but also those that may be necessary for future migration of habitats.

Whether habitats can persist in the face of climate change may depend on available land upslope that can allow habitat migration, as shown below.



Non-native species may outcompete for space and food with native species

The presence of non-native species is an ongoing battle and most coastal and inland areas contain species that were intentionally introduced, such as agricultural crops, or unintentionally introduced. Because these non-native species may have fewer predators, they may out-compete native species for food and habitat. Significant resources are expended to limit the spread of these exotic species in order to preserve the integrity of the natural systems. If native species are stressed by climate change impacts, they may be even less resistant to exotic species. Additional efforts will be necessary to stem the spread of invasive plants and animals in the face of climate change.

Species such as nutria, Brazilian pepper, and lionfish are considered exotic species within the Gulf of Mexico and can threaten native species. Photos: eattheweeds.com, scgov.net, floridasportsman.com

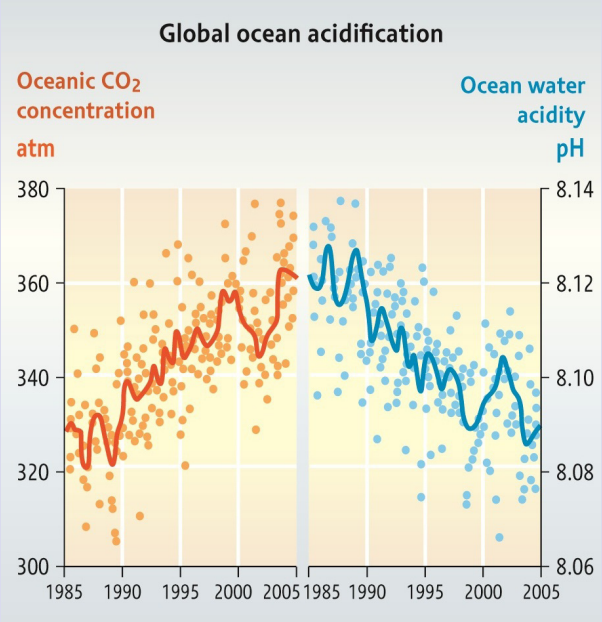
Ocean Acidification

Ocean acidification is the process by which the Earth's oceans become more acidic, as indicated by a lower pH value, as a result of absorbing carbon dioxide (CO_2). This can have severe consequences for marine life such as oysters, mussels, and coral reefs.

Oceans serve as a "sink" for carbon dioxide

Oceans are often considered a "sink" for carbon dioxide (CO_2) - a greenhouse gas that is emitted during the burning of fossil fuels, as well as through other processes. The oceans absorb between 1/3 to 1/2 of the man-made CO_2, with additional absorption by the Earth's atmosphere, as well as some plant communities such as wetlands. However, despite the vast size of the oceans, their ability to take up greenhouse gases without adverse consequences is limited.

When CO_2 is absorbed in ocean water, it dissolves into smaller molecules, forming carbonic acid. In the process, a positive Hydrogen (H^+) ion is released, causing a decrease in the ocean pH. The pH scale ranges from 0 (very acidic) to 14 (very basic). The average pH of the ocean is 8.2 which is slightly basic. The oceans have maintained a relatively stable pH for millions of years, but, in the past two centuries, the pH has dropped to 8.1 or lower in some areas. While this decrease of 0.1 may seem small, it represents a 25% increase in acidity. Even seemingly small decreases in pH can have large and harmful effects on marine life.



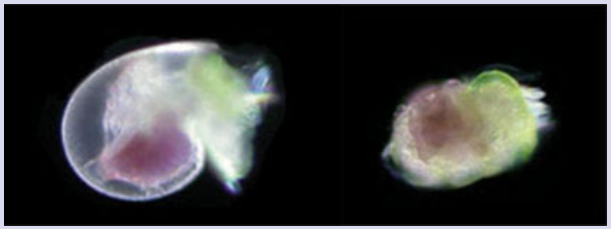
As the concentration of CO_2 in the ocean increases, the pH of the water lowers, leading to more acidic conditions. Source: IPCC, 2007

Acidification threatens marine creatures

Many marine plants and animals, such as shellfish, algae, and corals, create hard exterior structures or exoskeletons made from calcium compounds found in ocean water. For this calcification process to occur, these shell-building organisms require a saturation of specific compounds and a specific pH in the ocean. When there are higher levels of CO_2 in the water, this can disrupt the balance, leading to reduced or slower rates of calcification and even dissolving of shells or exoskeletons. Scientists around the world are already observing these effects in marine species.

Damage found in young and adult organisms

Ocean acidification can cause deformities in larval stages of organisms, reducing the number of viable adults. This is a concern as many of these organisms are an important food source for humans, as well as other marine animals. In some species, acidification can also lead to reductions in metabolism, immune system, and sensory functions.



Effects of acidification include deformations in abalone larvae (above) and bleaching of coral reefs (below). Photos: Maria Byrne, University of Queensland

Coral reefs support numerous organisms and provide protection for coastal communities against storms and waves. Corals that are stressed due to more acidic and possibly warmer waters, may release the beneficial organisms that support their growth and give them their bright colors, leading to a condition know as "coral bleaching."

Additional Gulf of Mexico Impacts

Communities within the Gulf of Mexico may experience climate change impacts differently than other areas throughout the world. The unique characteristics of the region, as well as what adaptation strategies are implemented and what the local priorities are, will determine whether impacts are moderate or severe.

Land subsidence exacerbates sea level rise

Some communities in the northern Gulf of Mexico, especially along the Mississippi River Delta, may be particularly susceptible to sea level rise due to land subsidence. Subsidence, or sinking, occurs when the level of the land lowers relative to the level of the sea. This can be caused by activities such as:

- Oil and gas extraction,
- Mining of natural resources,
- Dissolution of limestone, and
- Pumping of groundwater.

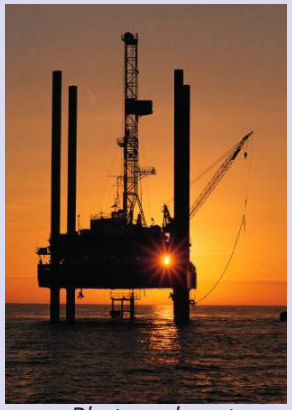
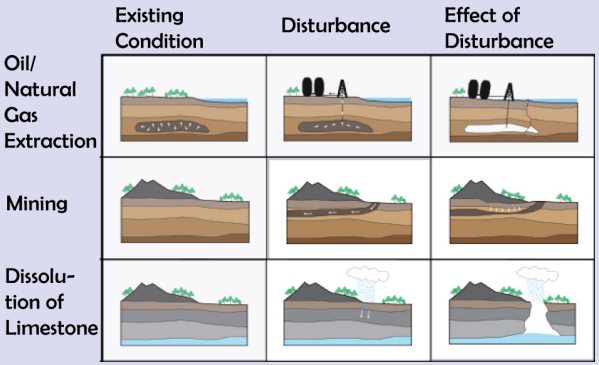


Photo: polarsat.com

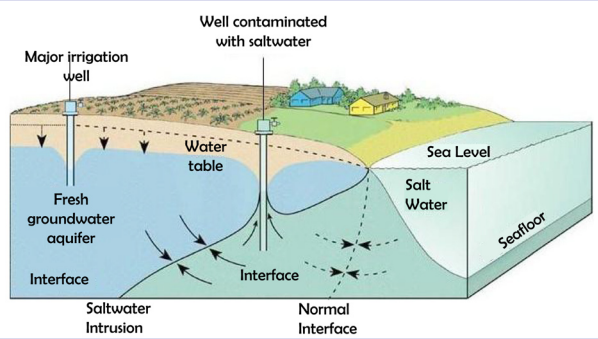
These activities can create pockets of air or unconsolidated areas below the Earth's surface, leading to sinking of the land area, resulting in a higher relative sea level rise than in areas without subsidence. Within the northern Gulf of Mexico, subsidence is primarily caused by extraction of oil and natural gas. There are currently more than 3,000 oil and gas platforms in the Gulf of Mexico region and nearly 46,000 miles of pipelines. While this is an important economic driver, it may lead to greater local impacts of sea level rise. There is also some evidence that suggests that mean sea level in the Gulf of Mexico is also rising faster than global trends over the past 60 years, potentially due to the characteristics of the gulf as a large, shallow, semi-enclosed basin.



Examples of three activities that can cause land subsidence, resulting in a settling or sinking of the land surface, leading to higher relative sea level rise. Adapted from Michael Petty via wikimedia commons

Saltwater intrusion impacts drinking water

Over-pumping of groundwater, impacts from storm events, and the construction of canals that alter the natural hydrology can lead to lowered water tables and potential saltwater intrusion. This occurs when denser, salty water pushes into freshwater areas of the underwater aquifer, threatening the long-term viability of fresh groundwater sources.



Saltwater can enter fresh portions of the aquifer, contaminating wells used for irrigation or drinking water. Graphic adapted from studyblue.com

Gulf wetland losses particularly severe

Urban development has led to losses of coastal and freshwater wetlands worldwide, but the losses have been greater proportionally in portions of the Gulf coast. Texas has lost more than 50% of its wetlands in the past 200 years. The state of Louisiana loses a football field-sized area of wetlands every hour. These wetlands provide protection for coastal communities so their destruction can increase the severity of impacts from storms and extreme events.

Wetland losses have occurred in many Gulf coast communities. Photo: nrcs.usda.gov

Gulf of Mexico Case Studies and Activity Codes

This handbook was developed to highlight activities and projects that address habitat resiliency to climate change and other impacts in coastal communities around the Gulf of Mexico. Other communities and agencies can learn by reviewing the techniques and strategies that are summarized in this handbook. Not every strategy will work in every community, however, many techniques or projects could be adapted to address the local characteristics and may lead to improved resiliency of habitats in your community.

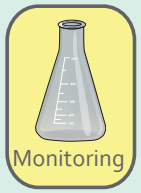
Case studies provide brief project summaries of many Gulf habitat resiliency efforts

Each case study includes a background on the local project area as well as the ecological challenges being addressed. The managing entity, as well as project partners, are identified by logo or within the text. A brief background on project goals and methodology is discussed, as well as how that project strives to address climate change and habitat resiliency. Representative photos, graphics, and maps support the written descriptions. When applicable, a link to a document, web page, or other materials is included. Other references can be found in the "Recommended Readings" section. A contact e-mail address is also provided to allow readers to communicate with project managers and learn more about how projects could be implemented in their community.

Many projects described in this document employ similar activities for developing and implementing resiliency strategies. The following codes help to identify a similar process or approach that is used. Many projects may also involve multiple steps. In that case, the dominant activity is used. The following provides a brief explanation of the planning steps and activities used by communities around the Gulf of Mexico.

Planning includes various forms of investigation and learning. It may include researching historical events to understand how ecological systems have functioned over time, or developing strategies for future impacts specific to a local community.

Mapping refers to efforts to visually portray current and potential future impacts of climate change. This may include developing maps of areas that will be inundated by sea level rise or where habitats may migrate. Maps may be geared towards planners, environmental managers, or the general public.



Monitoring is the process of gathering environmental data, such as water quality or land elevations, in order to track the health of an area. It may be used to establish baseline conditions or to track impacts from various stressors.

Restoration is the return of an ecosystem to a state prior to disturbance. It may involve removing exotic plants, planting native plants, or restoring natural hydrology to recreate a habitat. It may also entail manipulating an existing habitat so that it provides more environmental benefits such as pollution reduction or carbon storage.

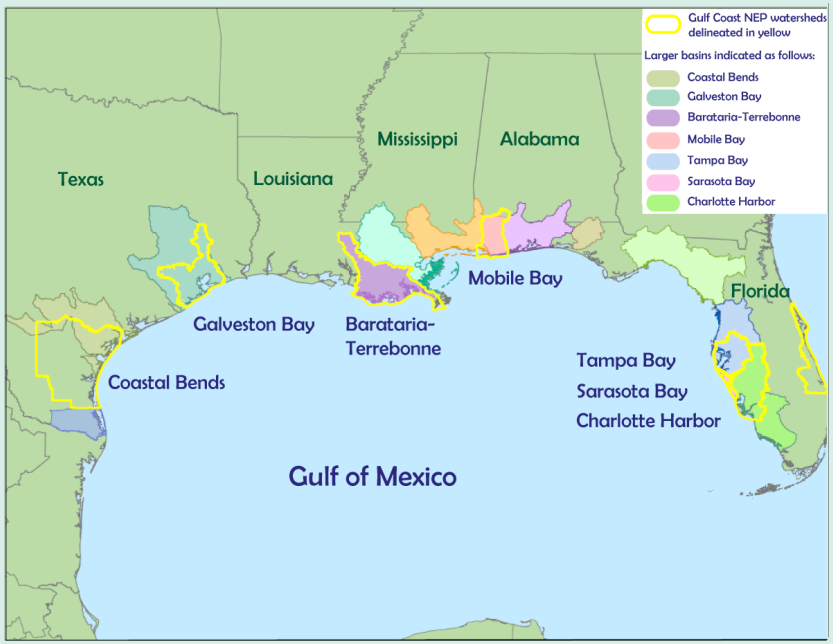
Adaptation involves actions or strategies to improve the resiliency or reduce the vulnerability of a habitat or ecosystem to impacts such as climate change. In this document it refers to the implementation phase and may involve physical manipulation of the environment.

Land purchase or acquisition includes purchasing tracts of land or conservation easements that limit the activities that occur on the land. This may include upland areas that are protected to allow coastal habitats to migrate inland with sea level rise. These areas may also undergo restoration or maintenance in the future.

Outreach involves educating and engaging the public or specific stakeholder groups to inform, gather information, or empower to take action on an important environmental issue.

National Estuary Programs

The National Estuary Program (Program) is a network of 28 individual estuary programs (NEPs) along the Atlantic, Gulf, and Pacific coasts and in Puerto Rico that have been designated as "estuaries of national significance." An estuary is a semi-enclosed body of water where freshwater mixes with salt water from the sea. Estuaries are considered some of the most productive environments in the world and are valuable habitat as a "nursery ground" for young fish, crustaceans, and shellfish.



The seven Gulf coast NEPs are shown above. Their watersheds and program boundaries are outlined in yellow. The colored areas indicate major drainage areas along the Gulf coast. Source: adapted from Gulf of Mexico Program.

Habitat, water quality issues a common link

The Program was established as an amendment to the Clean Water Act in 1987. Each NEP is required to develop a Comprehensive Conservation and Management Plan (CCMP) that outlines specific targeted actions to address water quality, habitat, wildlife, and other challenges in the watershed. The location, size, and habitats vary widely between programs. Some NEPs are in urban, densely populated areas, while others are in mostly rural areas. However, loss of habitat and water quality degradation are common problems among all NEPs and watersheds across the country.

Programs focus on the watershed level

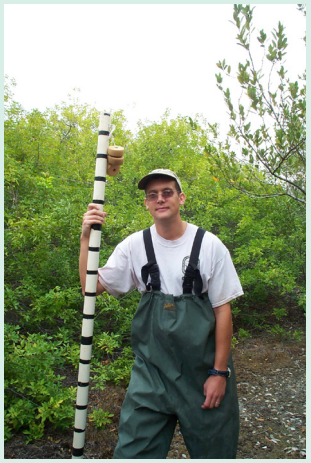
The 28 NEPs address local environmental conditions both within the estuary and its watershed. A watershed is the land area that drains into a body of water. NEPs emphasize the connection between what occurs on the land and the ways in which that can impact the estuary, both positively and negatively. The watershed scale allows the NEPs to look at "the big picture" of estuarine management.

Community-driven, partnership-based

Each NEP receives federal funding through the US Environmental Protection Agency and is required to match it with other sources such as state or local government funds, private contributions, or citizen donations. Each has a Management Conference made up of diverse stakeholders including citizens; local, state, and federal agencies; non-profits; academia; and private sector entities that work collaboratively to implement the CCMP. NEP priorities include:

- Sound scientific study,
- Strong partnerships ,
- Community involvement, and
- Effective action.

For information, visit: http://water.epa.gov/type/oceb/nep/about2.cfm



NEPs engage their community members in restoration activities (top), as well as scientific research (above). Photos: Holly Greening, Lindsay Cross

Re-Establishment of Maritime Chenier Ridge/Marshes Provide Bird Habitat in Port Fourchon, LA

Barataria-Terrebonne National Estuary Program

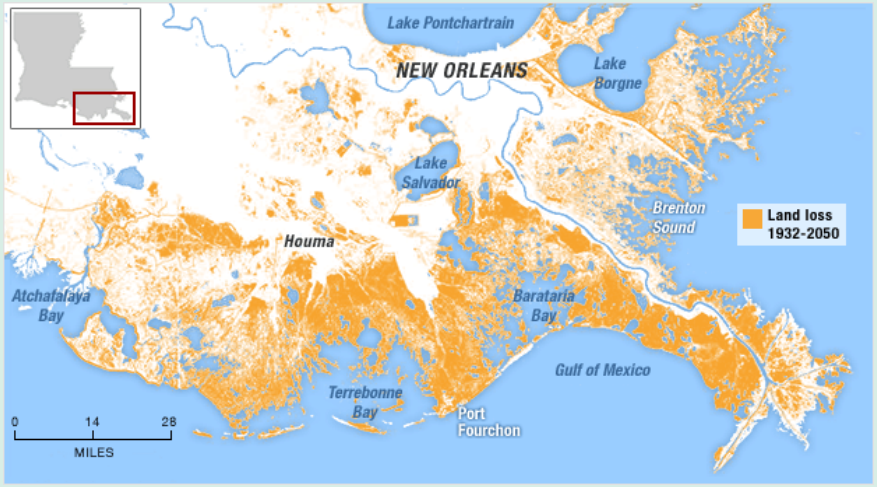
In 2001, the Barataria-Terrebonne National Estuary Program (BTNEP) and the Greater Lafourche Port Commission, an elected port commission that regulates waterborne trade and commerce within the 10th Lafourche Parish, fostered a partnership with other organizations to re-establish a chenier ridge and adjacent coastal marsh habitats in southeast Louisiana.

A chenier is a sandy or shelly beach ridge, typically three to 20 feet high, separated by mud-flat deposits with marsh and swamp vegetation. Cheniers are located in areas with low wave energy and gradually sloping, muddy shorelines. The name comes from the French word for oak, "chêne," which grow on the tops of the ridges in south Louisiana. They are important wildlife habitats, especially for migrating Neotropical songbirds that cross the Gulf of Mexico each spring to return to breeding grounds in the eastern US and Canada. Birds often use cheniers as places to feed and rest following their long journey across the Gulf of Mexico.

Neotropical songbirds such as the scarlet tanager rely on chenier ridges as resting and feeding areas during their annual migration. Photo: Gerold Morrison

Partners work to reverse wetland losses and accommodate sea level rise

Wetlands in Louisiana have been lost at an alarming rate - more than any other coastal area in the country. The US Geological Survey estimates that wetlands in Louisiana account for 40% of the remaining wetlands in the continental US, but 80% of the losses. These losses have numerous causes, including human disturbance and development, saltwater intrusion, storm damage, land subsidence, rising sea levels, and invasive species. These wetlands provide important habitat for fish and wildlife, supporting a $1 billion seafood industry. This multi-phase project will restore more than 100 acres of chenier ridge/ marsh habitat along some 12,000 linear feet.



The map above illustrates land loss since 1932 and predicted land loss through 2050 (combined) in southeastern Louisiana, which includes the BTNEP area. Source: coastal.louisiana.gov

Pipeline sediment delivery system uses beneficial dredged material

This project involves pumping earthen material into shallow open water areas to create elevated marsh and ridge areas. The technique, called pipeline sediment delivery (PSD), is a process that moves sediments harvested from existing deposits in river beds and offshore areas through a system of pipes to rebuild and renourish wetlands and natural ridges. Powerful pumps move the sediment and mud slurry to rebuild wetlands that have deteriorated.

The PSD technique allows ecosystem practitioners to restore natural ridges to precise elevations and slopes needed by native grasses and woody species. To create the maritime ridge system, the marsh elevations are shaped at 1.6 feet above sea level with the crown of the ridge at 8 feet.

Beneficial dredged material was used as a way of recycling sediments generated through dredging of waterways. This material may otherwise have been disposed of in landfills or off-shore disposal areas.

Ridge slope and differing elevations will provide habitat during sea level rise

Due to their gradual slopes and differing elevations, chenier ridge and marsh systems may be more resilient to climate change than other coastal marsh systems. Marsh areas with little vertical relief may become inundated with sea level rise, leading to plant die-backs as they become flooded. However, in areas with protected upslopes, such as maritime ridges, marsh plants are expected to gradually migrate upslope. Protection and restoration of these areas is important for long-term habitat benefits.

The lower-elevation muddy marsh area (above). Below, the maritime chenier ridge. Photos: BTNEP

Community members participate in planting

BTNEP organized volunteer planting events following construction of the ridge system. The lower marsh areas were planted with native herbaceous grasses such as smooth cordgrass, marsh hay cordgrass, and salt grass. These grasses can tolerate the harsh growing conditions of coastal Louisiana and help to stabilize sediments, reducing erosion. Woody plants, such as live oaks, hackberry, and red mullberry, were planted along the ridge. These woody plants are important to Neotropical migrant songbirds, providing habitat and food sources for many species of transient and resident birds.

BTNEP community volunteers plant smooth cordgrass on the marsh platform. Photos: BTNEP

Project serves as real-world experiment

BTNEP is partnering with the Natural Resources Conservation Service's Plant Materials Center to evaluate the planting success using different techniques. Scientists are planting many different species of plants to determine their ability to grow at different elevations and salt concentrations. This will help them determine which plants do best in which growing conditions. Marsh plants that do well in soils with higher salt content may be able to better tolerate sea level rise, for example. These results can be applied to future marsh restoration projects.

Scientist examine plants, such as marsh elder, sea ox-eye, and live oaks, growing along the maritime forest ridge. Photo: BTNEP

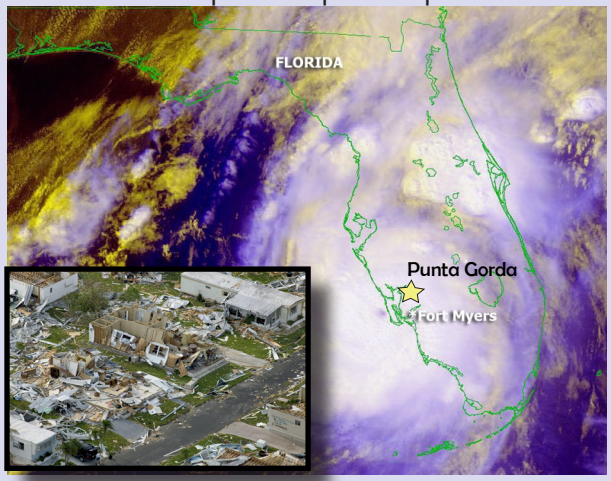
Major funding for this project came from the Shell Oil Company. Other partners included the Greater Lafourche Port Commission, National Oceanic and Atmospheric Administration, Louisiana Department of Natural Resources, Natural Resources Conservation Service, Gulf of Mexico Foundation, and Gulf of Mexico Program.

Contact: dean@btnep.org

City of Punta Gorda, Florida Develops Climate Change Adaptation Plan

Charlotte Harbor National Estuary Program

Hurricane Charley, a Category 4 hurricane and the strongest tropical system to hit Florida since Hurricane Andrew in 1992, made landfall unexpectedly in southwestern Florida on August 13, 2004. It caused significant damage to coastal and inland communities, including the small city of Punta Gorda which sustained a direct hit. The town - less than 19 square miles and with just under 17,000 people - has since become one of the most progressive municipalities in the United States with regards to planning for climate change. Punta Gorda is located within the watershed of the Charlotte Harbor National Estuary Program (CHNEP) and, working together, the city and CHNEP engaged the community in an extensive and successful effort to develop an adaptation plan.



Hurricane Charley making landfall at Punta Gorda and subsequent damage. Photos: FEMA (left), NOAA (right)

Team Punta Gorda rallies the community

CHNEP adopted a climate change adaptation component for its Comprehensive Conservation and Management Plan in 2008. Using a US EPA Climate Ready Estuaries grant, CHNEP teamed with the Southwest Florida Regional Planning Council (SWFRPC), City of Punta Gorda, and the citizen stakeholder group "Team Punta Gorda" to develop a climate change adaptation plan.

Games help citizens prioritize adaptations

The pilot project relied on extensive community involvement during a series of three public workshops. The project team used the following interactive games to engage community members and determine priorities and rankings of elements for inclusion in the adaptation plan:

- Vulnerability Game: rank vulnerabilities for the city and its inhabitants,
- Adaptation Game: recommended locations where possible adaptation strategies should take place, and
- Acceptability Game: provide level of agreement for various adaptation measures.

Participants show their level of agreement for adaptation strategies. Photo: CHNEP

Citizens identified 54 vulnerabilities and eight major areas of climate change vulnerability for the city, in order of priority:

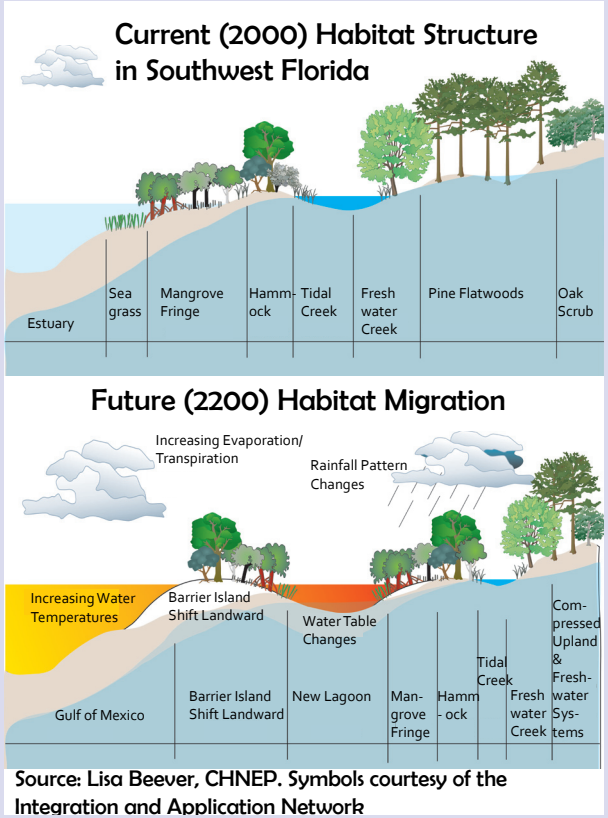
- Fish and wildlife habitat degradation,
- Inadequate water supply,
- Flooding,
- Unchecked or unmanaged growth,
- Water quality degradation,
- Education, economy and lack of funds,
- Fire, and
- Availability of insurance.

The participants then identified 246 climate change adaptations that correspond to ten major areas of climate vulnerability:

- Economy
- Financial
- Flooding
- Habitat
- Water Quality
- Education
- Fire
- Growth
- Insurance
- Water Supply

Scientists depict habitat migration patterns

Local scientists and habitat managers helped to explain how coastal habitats may migrate with climate change. The conceptual diagrams on the next page illustrate a migration pattern that may occur in Punta Gorda. That aided in developing adaptations.



Source: Lisa Beever, CHNEP. Symbols courtesy of the Integration and Application Network

Stakeholders define various strategies

Adaptation strategies for coastal erosion and sea level rise were broken into the following broad categories with example techniques:

- Armouring/Filling/Diking: shoreline stabilization or hardening techniques;
- Planned Relocation: moving development and infrastructure out of harm's way in a planned and controlled manner over time; and
- Redesign/Adaptation: strategies that allow for the use of vulnerable lands to continue, but that do not attempt to prevent impacts such as flooding.

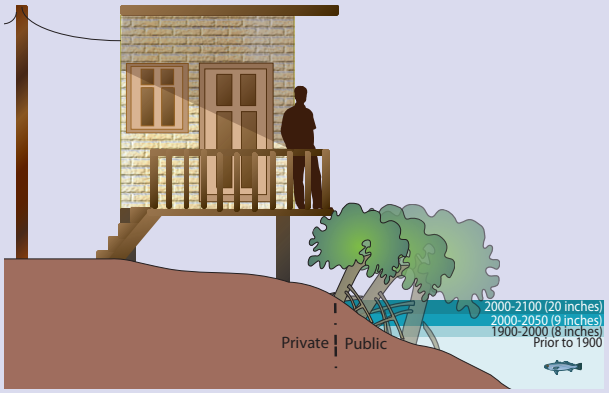
Citizens identify locations for adaptations

Workshop participants selected the best locations for specific adaptation strategies and then located the highest-ranked strategies on a map of their city.

The top agreed-upon adaptations for each area of vulnerability included:

- Seagrass protection and restoration;
- Xeriscaping and native plant landscaping;
- Explicitly indicating in the comprehensive plan which areas will retain natural shorelines;
- Constraining locations for certain high risk infrastructure;
- Restricting fertilizer use;
- Promoting green building alternatives through education, taxing incentives, and green lending; and
- Drought preparedness planning.

Stakeholders further developed some adaptation strategies such as rolling easements - a planned relocation strategy.

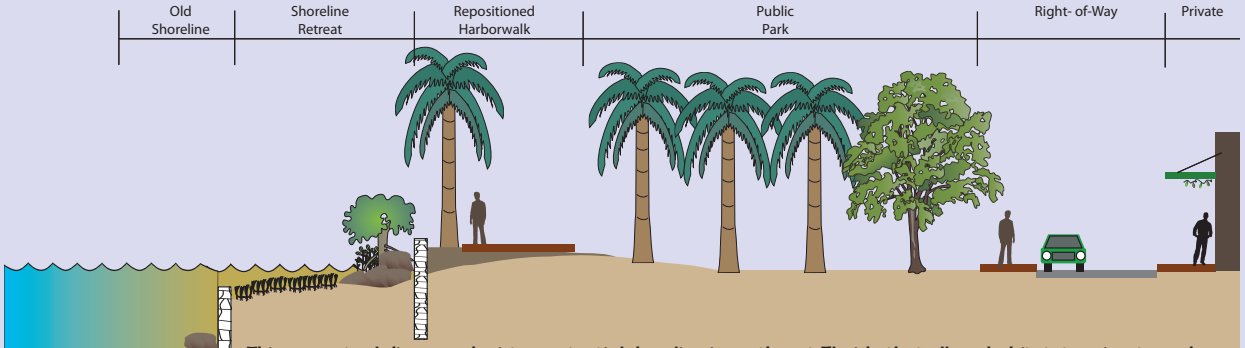


Rolling easements allow private property to be maintained until water levels reach high levels. Private parcels then become public and are allowed to recolonize with native habitats. The example above reflects moderate case scenarios. Source: Lisa Beever, CHNEP. Symbols courtesy of Integration and Application

Anticipating an increase of almost four feet of mean high tide levels by 2200, this may be a viable solution for some parts of the coast.

The adaptation plan is a living document that will be updated periodically. It is available at: http://www.cakex.org/sites/default/files/Punta%20Gorda.pdf

Contact: lbeever@swfrpc.org



This conceptual diagram depicts a potential shoreline in southwest Florida that allows habitats to migrate and important urban infrastruture and amenities to be protected. As sea level rises, the current shoreline becomes inundated, leading to shoreline retreat and migration of marsh plants. The area upslope may be developed as a public park, with infrastructure and private lands situated further from the coast.
Source: Lisa Beever, CHNEP. Symbols courtesy of the Integration and Application Network

Climate Change Vulnerability and Adaptation Opportunities for Southwest Florida Salt Marshes

Charlotte Harbor National Estuary Program

Southwest Florida, with its subtropical climate, is home to a unique salt marsh community that supports more than 300 plant and nearly 700 animal species. These marshes are vital for shoreline protection and provide numerous ecosystem services such as pollution reduction and carbon storage.

Within the Charlotte Harbor National Estuary Program (CHNEP) watershed, marshes have been impacted by development, pollution and changes in hydrology. However, almost 74% of the existing marshes are now protected. CHNEP developed a study to:

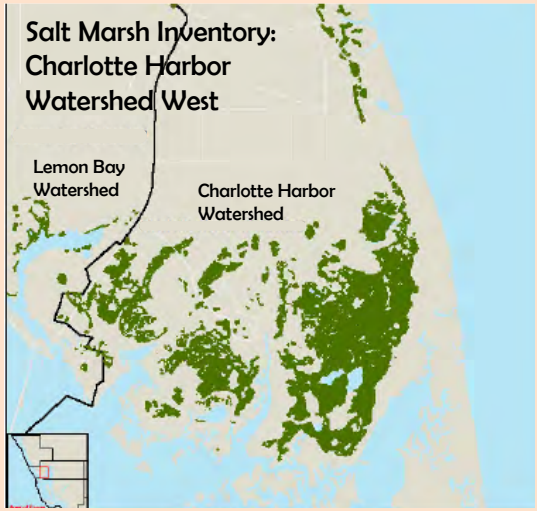
- Inventory the extent and nature of salt marshes in CHNEP study area;
- Determine the vulnerability of those marshes to climate change;
- Identify opportunities for avoidance, minimization, mitigation, and adaptation (AMMA) to climate change; and
- Recommend strategies to implement AMMA options.

Leatherfern marsh. Photo: Whitney Gray

Predominant salt marsh types in southwest Florida include the following. They are arranged roughly from low to high marsh.

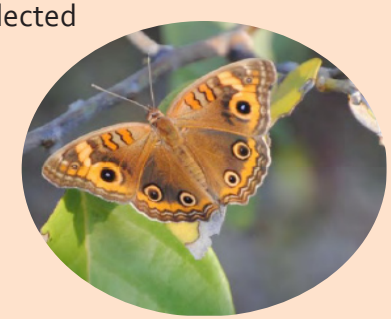
Shrub mangrove photo: James Beever III. All other photos: Whitney Gray

Scientists in Charlotte Harbor mapped the location and extent of the salt marsh types throughout the region and developed coverage maps. The following is an example of an inventory map in western Charlotte Harbor. Salt marsh is shown in green.



Flora and fauna surveys reveal marsh health

Once the physical extent of marshes was completed, scientists visited 49 marsh systems and collected information on species utilization, water quality, and a functional assessment of the marshes.



Mangrove buckeye butterfly. Photo: Whitney Gray

Scientists developed species lists for fish and wildlife observed in the marshes. One technique for counting small fish is to use a fish viewing window, shown right. During 68 site visits, scientists observed the following species:

James W. Beever III demonstrates the fish viewing window. Photo: Whitney Gray

- 11 mammals
- 82 birds
- 9 reptiles
- 4 amphibians
- 119 arthropods
- 22 fish
- 26 mollusks

Charlotte Harbor salt marshes rated highly

Three wetland functional assessment techniques were used to determine the relative health of the marshes studied. These included the Wetland Rapid Assessment Procedure (WRAP), Uniform Mitigation Assessment Method (UMAM), and Hydrogeomorphic Approach (HGM). They quantitatively measure factors such as:

- Wildlife utilization,
- Habitat support,
- Community structure and wetland canopy,
- Indicators of hydrology,
- Water quality, and
- Surrounding land uses.

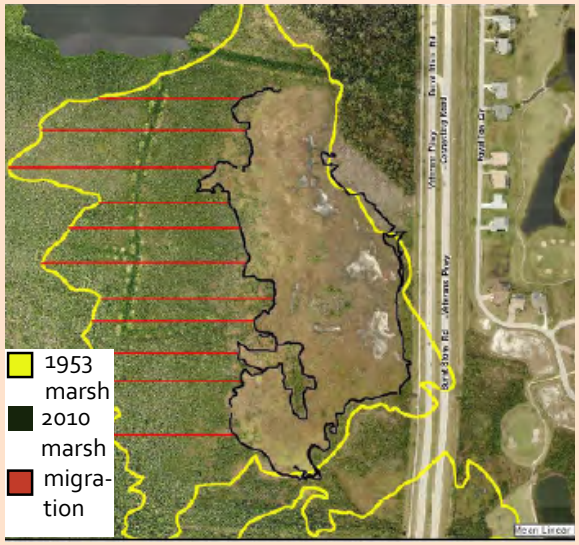
Overall, the quality of salt marshes studied in the CHNEP area is rated as very good.

Climate change may alter wetland hydrology

Climate change may lead to large-scale changes in coastal vegetation resulting from:

- Warmer air and water temperatures,
- Sea level rise,
- Saltwater intrusion and salinity changes,
- Flooding and droughts,
- Intense storms and hurricanes,
- Erosion and changes in sediment accretion, and
- Water quality pollutants and algal blooms.

An important consideration is whether coastal marshes will have the ability to move landward or accrete enough sediments to keep up with sea level rise. Migration has been observed at some locations, but barriers to movement, such as sea walls, bulkheads, and roads have prevented movement, leading to salt marsh losses.



Changes in salt marsh coverage between 1953 and 2010 at Charlotte Harbor Preserve State Park. Source: CHNEP

Inundation above 2012 Baseline	% Area of Salt Marsh Inundated	# Acres of Salt Marsh Inundated
1 Foot	52%	7,785
2 Feet	73%	10,819
3 Feet	75%	11,103

Inundation scenarios and potential impact on salt marsh in CHNEP area. Data source: 2007a IPCC publication

Sea level rise may result in greater losses as marshes become inundated. The following adaptation strategies were developed for marshes in southwest Florida:

1. Maintain existing marsh migration corridors and identify new corridors.
2. Acquire/protect inland/landward buffer zones to provide locations for migration.
3. Restore existing salt marshes through exotic vegetation removal, backfilling ditches, and removing barriers to tidal connection.
4. Use natural vegetation for shoreline stabilization rather than hardening.
5. Re-engineer existing vertical shorelines with permeable stabilization materials.
6. Restore impaired water flows to enhance sediment supply to salt marshes.
7. Repair abandoned road corridors using permeable materials.
8. Backfill mosquito control ditches.
9. Backfill or re-slope shorelines of large pits to serve as marsh migration corridors.
10. Add sediment in specific locations to enhance marsh building processes.

Document available at: http://tinyurl.com/llr9xjv

Contact: lbeever@swfrpc.org

Making Marshes That Will Withstand Sea Level Rise in Nueces Bay, Texas

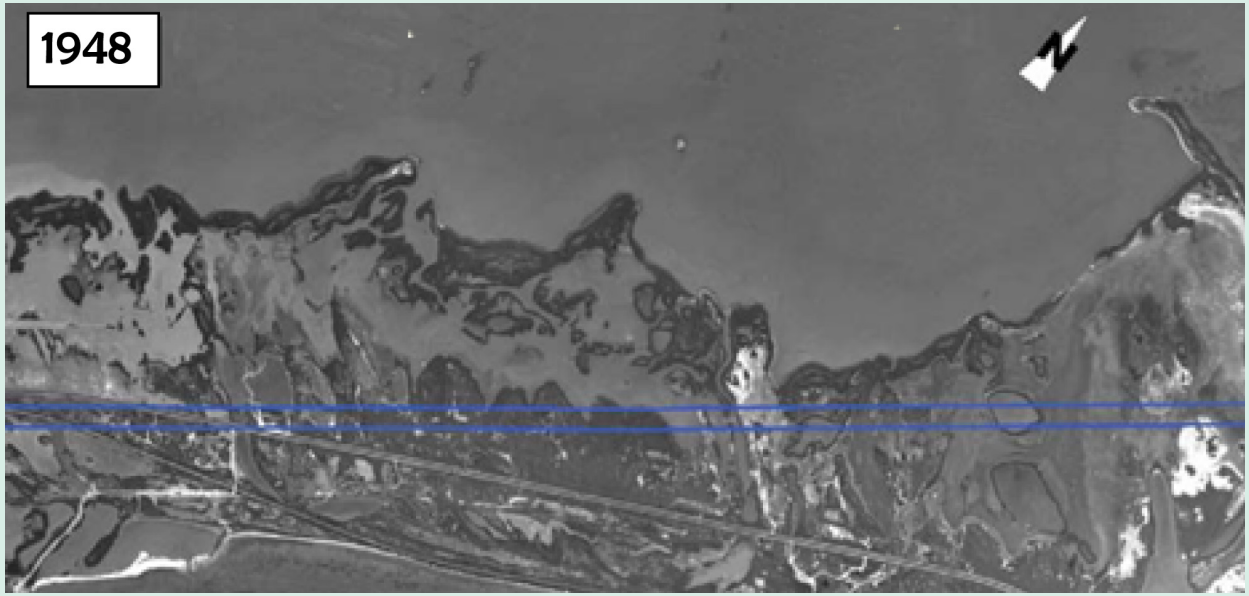
Coastal Bend Bays & Estuaries Program

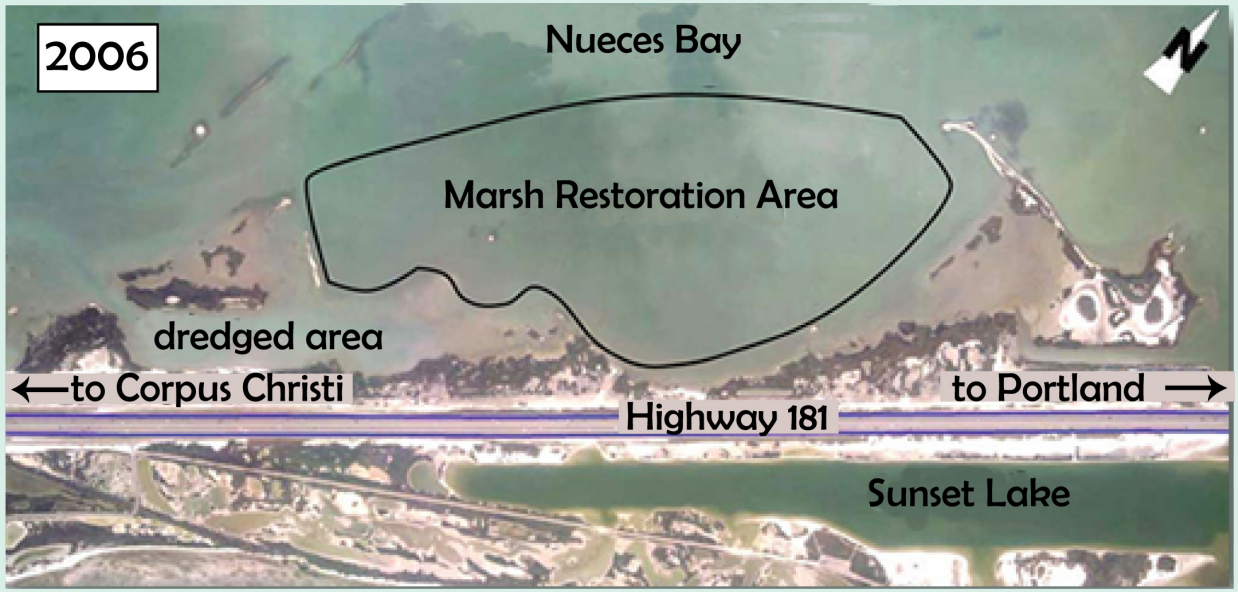
The Coastal Bend Bays & Estuaries Program (CBBEP) in Corpus Christi, Texas is conducting a major restoration effort that will restore more than 160 acres of marsh and will be resilient to future sea level rise.

The project is located near the Nueces Bay Causeway that connects the cities of Corpus Christi and Portland. Prior to the mid-20th century, this area had extensive intertidal marsh which is essential habitat for juvenile fish, shrimp, and crabs and is a feeding area for larger fish and birds. During construction of the causeway in the late 1940s, more than 180 acres of marsh were destroyed. Since that time, as many as 160 additional acres of marsh have been lost due to erosion and subsidence.

Causeway area selected for marsh creation

The CBBEP and its project team, led by engineers with HDR, identified the area north of the Nueces Bay Causeway as a priority restoration site due to its importance to the ecosystem and the growing concerns with erosion. Aerial photos showed the extensive marsh loss that occurred between 1930 and 2000, resulting from construction, dredging, and erosion. By 2000, only a few isolated pockets of marsh remained along the shoreline.





The photos above show the Nueces Bay area in 1948 and 2006. The 1948 aerial is prior to construction of the current causeway which wiped out about 180 acres of marsh. The 2006 photo shows the 160-acre restoration area that will be converted from an open-water complex to a natural marsh area. Photos: HDR, Lammon Aerial Photography

Sediment quality an important factor

The project team began restoration plans in 2005. It conducted extensive field work, assessing existing marshes in the area and sampling the sediment quality to determine the best location for the restoration project. Sediment type is an important consideration when designing restoration projects and the project team ensured that the constructed marsh would mimic a natural marsh system.

Multi-phase project designed

The project team identified a 160-acre open water area that could be converted in phases into an intertidal system. Construction began in July 2010 on a 76-acre complex. A series of channels were created by scooping out small sections of the bay bottom. This material was then used to form higher areas, or terraces, suitable for marsh growth. The terraces were planted with native marsh grasses by volunteers. The second phase added another 84 acres of marsh between the constructed terraces and the outermost berm.

Higher elevations will ensure longer-term resiliency against sea level rise

The project has been designed with several elements that will improve resiliency. A rock revetment will be constructed around the perimeter to serve as a wave break. This will protect the marsh areas from wave energy and increase the project lifespan.

The man-made marsh terraces were built at a higher elevation than currently needed in order to accommodate sea level rise. The completed project will incorporate various depths and zones that will provide essential marsh habitat for fish and wildlife species now and into the future.

Contact: jtunnell@cbbep.org

Left: Volunteers plant native marsh grasses. Photo: Jace Tunnell. Above: This aerial photo from March 2011 shows the terraces and berms created during the first phase of marsh restoration. A second phases will create additional marsh complex between the terraces and the top berm. Photo: HDR, Lammon Aerial Photography

Recovery Act: Restoring Estuarine Habitats in West Galveston Bay, Texas

Partners of the Galveston Bay Estuary Program

Restoration

The Recovery Act: Restoring Habitats in West Galveston Bay, Texas project restored 328.5 acres of intertidal marsh complex within the Carancahua Cove (aka Galveston Island State Park) and Jumbile Cove areas of West Galveston Bay. It received funding from the Texas General Land Office (GLO), NRG Energy, Texas Parks and Wildlife Department (TPWD), and the American Recovery and Reinvestment Act (ARRA), administered through the National Oceanic and Atmospheric Administration (NOAA).

Map of Galveston Bay and restoration sites. Source: GBEP

The project was developed by TPWD, in coordination with and in support of the Natural Resource Uses Subcommittee of the Galveston Bay Council - the advisory committee of the Galveston Bay Estuary Program. It was jointly managed by TPWD and GLO.

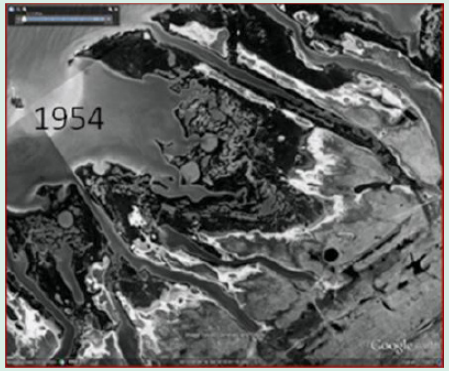
Habitat loss in West Galveston is severe

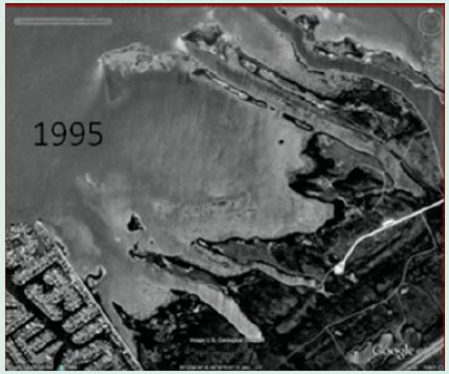
Coastal wetlands in Texas are highly productive biologically. They serve as nursery grounds for more than 95% of the recreational and commercial fish species found in the Gulf of Mexico, including brown and white shrimp, blue crab, Gulf menhaden, sand seatrout, southern flounder, and red drum that flourish in these protected waters.

Red drum: fishersbaycharters.com

These wetlands also perform other functions, including temporarily retaining pollutants, storing runoff during heavy rainfall events, and reducing damages from storm events by acting as a buffer between shoreline and inland areas. Despite the numerous societal benefits, coastal wetland loss in Texas and, especially, in the Galveston Bay system, is severe. The Galveston Bay system lost a net of nearly 35,000 acres (20%) of its wetlands and 1,800 acres (70%) of its seagrass between the 1950s and 1985, much of this occurring in West Galveston Bay. Wetland loss is continuing in the Galveston Bay system and is due to many causes, including:

- Dredging,
- Stream channelization and filling,
- Subsidence,
- Sediment diversion,
- Saltwater intrusion,
- Erosion,
- Hydrologic alteration, and
- Sea level rise.



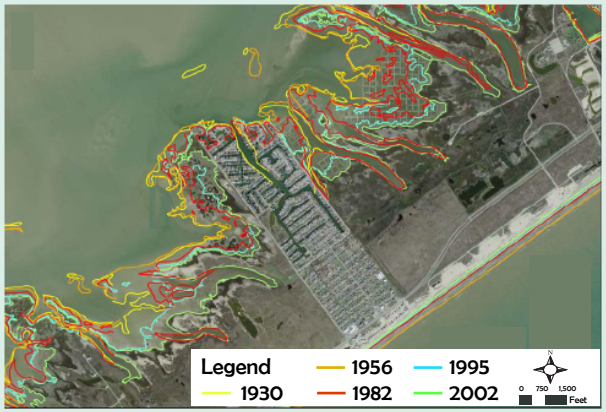


Photos: downloaded from University of Texas Bureau of Economic Geology

Aerial photographs document coastal wetland loss at Carancahua Cove. The area historically consisted of high and inter-tidal marsh with tidal inlets (top photo, 1954). These areas have been converted to mostly open water (bottom photo, 1995).

Shoreline changes, erosion, and sea level rise threaten marsh and seagrass habitats

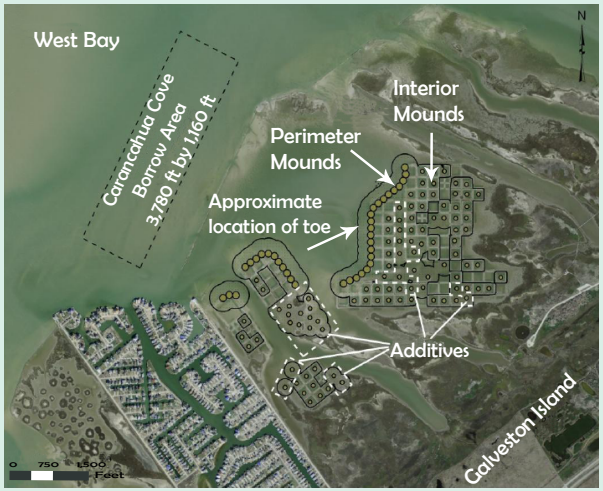
Shorelines along West Galveston Island have changed. Historically, a continuous band of emergent wetlands lined the island, followed by a thick fringe of seagrass in the shallow open waters. These habitats were protected by features such as shoreline ridges and vegetated land spits. However, rates of erosion and subsidence have increased, posing significant threats to the marsh and adjacent habitats. Average rates of erosion along West Galveston Bay shorelines have increased from 0.8 ft/yr during the 1852-1930 time period to 2.1 ft/yr between 1930-1982. Land subsidence between 1-2 feet during the 20th century has increased the vulnerability of the marsh systems to erosion during winter and tropical storms. Sea level rise has also contributed to the drowning and fragmentation of the marsh.



Shoreline changes at Carancahua and Jumbile Coves during five time periods. Source: TPWD; historical shorelines downloaded from the University of Texas Bureau of Economic Geology

Restoration technique proven successful in other restoration projects

This project sought to restore marsh in West Galveston Bay using a restoration technique which has been successfully applied at nearby sites. It involves the pumping of dredged material from a borrow site to create gently-sloping marsh mounds at specific elevation ranges. Gradual slopes, between 18:1 and 32:1, are more stable, more resistant to wave action, and more conducive to establishing a wide marsh fringe. A portion of dredged material is placed above the intertidal elevations to allow for soil compaction and relative sea level rise, and to allow migration of intertidal marsh to higher elevations as the water levels rise.

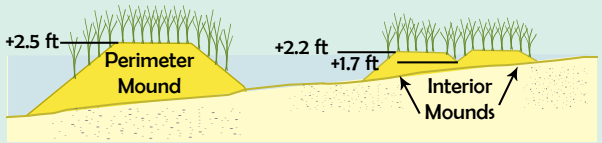


Restoration design for Carancahua Cove. Sediment used for marsh mounds was hydraulically dredged from the nearby borrow area. Source: TPWD

At Carancahua Cove, 36 perimeter and 103 interior mounds were constructed within a 198.5-acre area. At Jumbile Cove, 19 perimeter and 92 interior mounds were constructed within a 130-acre area. A total of 602,000 cubic yards of dredged material was used.

Perimeter mounds protect interior mounds and marsh grass

Perimeter mounds were constructed at a higher elevation than interior mounds to provide protection for interior mounds and planted marsh grasses. Some erosion of these waterwards mounds is anticipated and will provide a sediment source and an opportunity to nourish other sediment-starved marshes adjacent to the proposed restoration areas. For this reason, they are referred to as a "semi-sacrificial marsh ridge." This technique is an alternative to constructing a hard structure such as a geo-textile tube breakwater around the project area to protect the interior features and planted elements.



Construction (pre-settlement) elevations for the marsh mounds at both sites. Source: adapted from TPWD

The restoration design for the two sites includes the high range of intertidal marsh and sand flat/salt pan elevations. These elevations and gradual slopes will allow the marsh to migrate upslope in response to sea level rise. TPWD restoration projects similar to this one incorporate sea level rise projections to increase long-term success.

Marsh mounds planted with smooth cordgrass

Following construction, the mounds were planted with 206,000 plugs of smooth cordgrass (*Spartina alterniflora*). The majority of the plants were planted by a contractor, with ~22,000 plugs planted using volunteers from agencies, non-profits, and corporations. Planting densities were based on the location within the project that was being planted. Higher energy areas received higher planting densities.

Contractors plant smooth cordgrass on a mound to stabilize the sediments and create habitat. Photo: GLO

Erosion, marsh survival and other project aspects monitored

Following completion in 2012, the project was monitored for the following criteria:

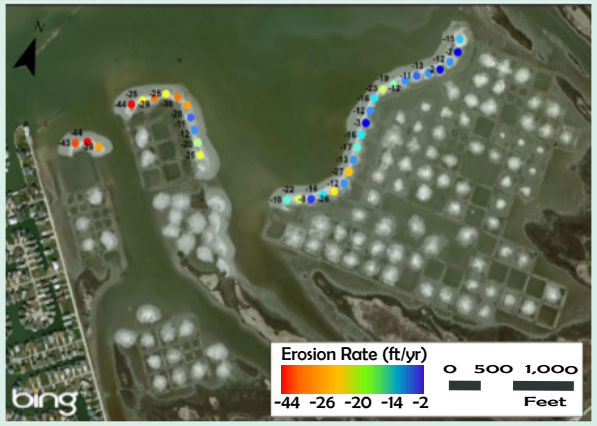
- Plant survival and expansion,
- Erosion rates,
- Changes in side slopes, and
- Mound settlement.

Aerial photography will be utilized to monitor long-term aspects of the project such as marsh accretion and/or erosion.

Based on monitoring, scientists made the following observations:

- Plant survival ranged from 80.5% to 92.5% between all sites. Plant survival was slightly higher on the interior mounds than perimeter mounds at both sites.
- Slopes on perimeter mounds generally tended to become steeper with time due to exposure to direct wave action.
- Erosion rates varied significantly depending on mound location, ranging from 2 ft/yr to 90 ft/yr during the initial post-construction period. In general, perimeter mounds had higher rates of erosion than interior mounds.
- Erosion rates peaked following construction but have since decreased due to slope equilibration, establishment of vegetation, and the accumulation and cementation of shell, improving stability of the perimeter mounds.

Documentation of marsh survival and expansion at Carancahua Cove interior mound 63. The photos show the same area approximately 8 months (top), 17 months (middle), and 22 months (bottom) post-planting. The green marker (circled in red for emphasis) serves as a point of reference for documenting the same approximate location and line of site, demonstrating the continued growth of the planted Spartina alterniflora. *Photos: TPWD*



Carancahua Cove perimeter mound erosion rates (as-built to November 2012). Source: TPWD, Image: USGS

Project helps stimulate local economy

The project is performing as designed. In addition to improving the estuarine environment, throughout the nearly 19-month project period, more than 45,000 man hours were expended - creating or retaining 65 jobs, as well as other volunteer and community outreach opportunities.

Reference: Recovery Act: Restoring Estuarine Habitats in West Galveston Bay, Final Report. Prepared by Cherie O'Brien, TPWD. Additional information at: http://www.glo.texas.gov/GLO/agency-administration/budget-expenditures/ARRA.html

Contact: cherie.obrien@tpwd.texas.gov

Mon Louis Island, Alabama Shoreline Stabilization and Habitat Creation Project

Mobile Bay National Estuary Program

Mon Louis Island is a coastal community south of Mobile, Alabama on the western side of Mobile Bay. It is approximately two miles wide and six miles long, with an average elevation of only seven feet. Erosion has been a persistent problem that threatens coastal habitats as well as built environments. The Mobile Bay National Estuary Program (MBNEP) designed a project to help stabilize the shoreline and create habitat, while resisting impacts from climate change and sea level rise. The project, which has been approved by the State of Alabama as a technological demonstration project, involves shoreline and offshore components that will serve multiple roles.

Mon Louis, located on the western side of Mobile Bay, is indicated by the yellow star in the map above. Source: adapted from GraphicMaps.com

Breakwaters stabilize beach areas

The project involved intertidal placement of four 40-foot rock breakwaters along a 700-foot portion of the beach. Behind these, sand fill was placed to create scalloped pocket beaches. This was chosen as an alternative to bulkheads or continuous riprap armouring along the shoreline. The breakwaters will protect the headlands from erosion from wind- and ship-generated waves. The structure will also provide habitat complexity and attachment areas for oysters.

The photos above show the completed intertidal area, plus a closeup of the northern two breakwaters, three months after construction. The scalloped profile of the pocket beaches can been seen. Photos: Tom Herder

The offshore reef structures are shown as two circular features in the photo above. These provide an attachment site for oysters (right) which filter the water and provide food for fish and invertebrates. Photos: Tom Herder, www.gulflive.

Offshore reef structures provide habitat

Two submerged rock reef structures approximately 80 feet in diameter were placed 600 and 800 feet from shore to provide habitat for oysters, fish, shellfish, and invertebrates. They also serve to attenuate wave energy and stabilize the shoreline.

With increased sea level, it is anticipated that the shoreline protection properties may be compromised, however, the habitat value of all installed rock structures will be enhanced and will continue to provide habitat for oysters and other shellfish even as shorelines retreat.

Contact:therder@mobilebaynep.com

Habitat Creation at North Lido Beach, Florida Limits Future Storm Impacts

Sarasota Bay Estuary Program

Habitat restoration is an important initiative for the Sarasota Bay Estuary Program (SBEP). While Sarasota Bay is the smallest estuary of the three Florida Gulf Coast NEPs, it has completed many coastal habitat projects with support from an active and progressive environmental community.

A recent habitat restoration project was completed at North Lido Park on Lido Key that will help to limit impacts from storms. The park is contiguous with both the Gulf of Mexico and Sarasota Bay (Pansy Bayou) and is near a popular tourist destination.

The project location is noted in red and the Sarasota Bay watershed in green. Source: adapted from SBEP

The park offers a range of multi-purpose passive recreational opportunities for the public and was restored to improve water quality and provide wildlife habitat.

Wetlands were created

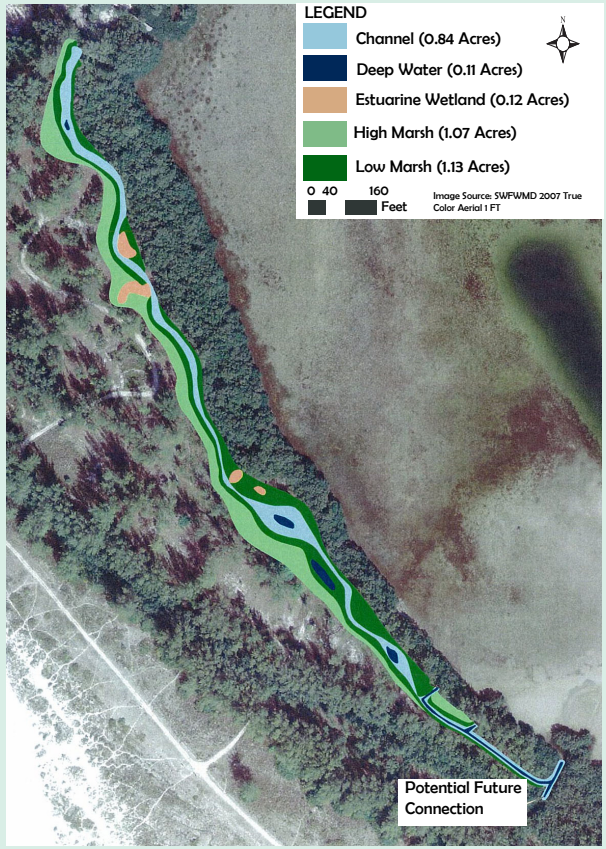
The primary restoration activity was wetland creation. This was accomplished by scraping down upland areas landward of the existing mangrove fringe and mean high water line. The existing upland areas were dominated by exotic vegetation such as Brazilian pepper, carrotwood, and Australia pine; native upland communities were not lost. Two areas of uplands were preserved as coastal hammock. Three wetland zones were created at the following elevations:

- Channel (0.5 to -2.0 feet),
- Deep Water Habitat (- 3.0 feet), and
- Low Marsh (0.5 to 1.5 feet).

Tides incorporated into design

The created wetlands were designed to receive tidal influence to support a salt marsh community. A small tidal channel was created within the low marsh system (not directly adjacent to the mangroves) connecting it to an existing waterway on the south end of the site. This waterway ran perpendicular to both the existing shoreline and the proposed project. Connecting the created tidal creek to this waterway provided the hydrologic connection from the tidal flow to the created wetlands. This connection point was chosen to eliminate the need for dredging landward of the mean high waterline and to reduce the need for future maintenance.

The new tidal creek is connected to Sarasota Bay in an area protected by a mangrove outcropping, which will in turn reduce the risk of sedimentation and future maintenance.



The restoration plan (above) was developed by Scheda Ecological Associates, Inc.

The channel, shown right, extended to the northern end of the property and connected to an existing low area landward of the existing mangrove fringe and mean high water level. Deep water pools were excavated within the channel to create refuge areas for juvenile fish.

Fill material used to create micro-habitats

All of the fill material was contained on-site and was used to create several 20-30 foot tall rolling, coastal dunes within the upland portion, just landward of the created wetlands and the county's Gulf Beach Setback Line. Best Management Practices were used to prevent impacts to wetlands and surface waters. The dunes will provide further protection against storm energy and storm surge. Over time, the Pansy Bayou may breach into the tidal creek, so the project has been designed to evolve. Because of the differing elevations and the lack of artificial barriers, micro-habitats can establish and move and shift as sea level rise occurs.

Community volunteers plant natives

Community involvement was also an important component of this project. The SBEP organized two volunteer events to actively engage the community in restoring the park. A combination of salt marsh cordgrass, seashore paspalum, and sand cord grass was planted within the created wetlands. Other native species such as buttonwood, marsh elder, sea oxeye daisy, seagrape, and seashore paspalum were planted along the landward edge of the created high marsh.

Families plant native bushes along the tidal creek. Photo: Sara Kane

Park withstands Tropical Storm Debby

The newly-created restoration area was tested in June 2013 during Tropical Storm Debby which brought heavy rainfall and flood conditions into many coastal areas. The created tidal creek filled with water, but provided a buffer against flooding for the higher marsh areas. Ecosystem managers were pleased that the park proved resilient during this event and anticipate that it will continue to provide a buffer for upslope areas against flooding and sea level rise.

Major funding for the project was from the Southwest Florida Water Management District and US Fish and Wildlife Service.

Contact: jay@sarasotabay.org

Photos above shows the tidal creek following Tropical Storm Debby and entrance sign. Photos (above and far left): Jay Leverone

Visualizing Sea Level Rise and Storm Surge in Sarasota Bay Estuary, Florida

Sarasota Bay Estuary Program

The Sarasota Bay Estuary Program (SBEP) and its partners recognize that there will be potential long-term impacts of rising sea levels along the Sarasota estuary coast. In order to arm its partners with useful planning information, SBEP developed a web-based sea level rise viewer that allows ecosystem managers, as well as cities and counties, to view various sea level rise and storm surge scenarios within their area.

The viewer was a collaborative effort with Mote Marine Laboratory and the US EPA's Climate Ready Estuaries Program. SBEP and its partners began by holding technical workshops and discussion groups to test and introduce the web visualization tool to community leaders and the public. From there, an interactive web-based tool was developed using LiDAR data from the counties within the watershed.

The website allows users to customize their experience, selecting from various sea level rise and storm surge scenarios and either a terrain map or a Google Earth platform, to demonstrate how areas in their communities may be impacted. The sea level rise scenarios include one, three, and six feet of rise. Then six-foot increments of storm surge can be added to show seven, nine, and 12 feet of combined sea level rise and storm surge.

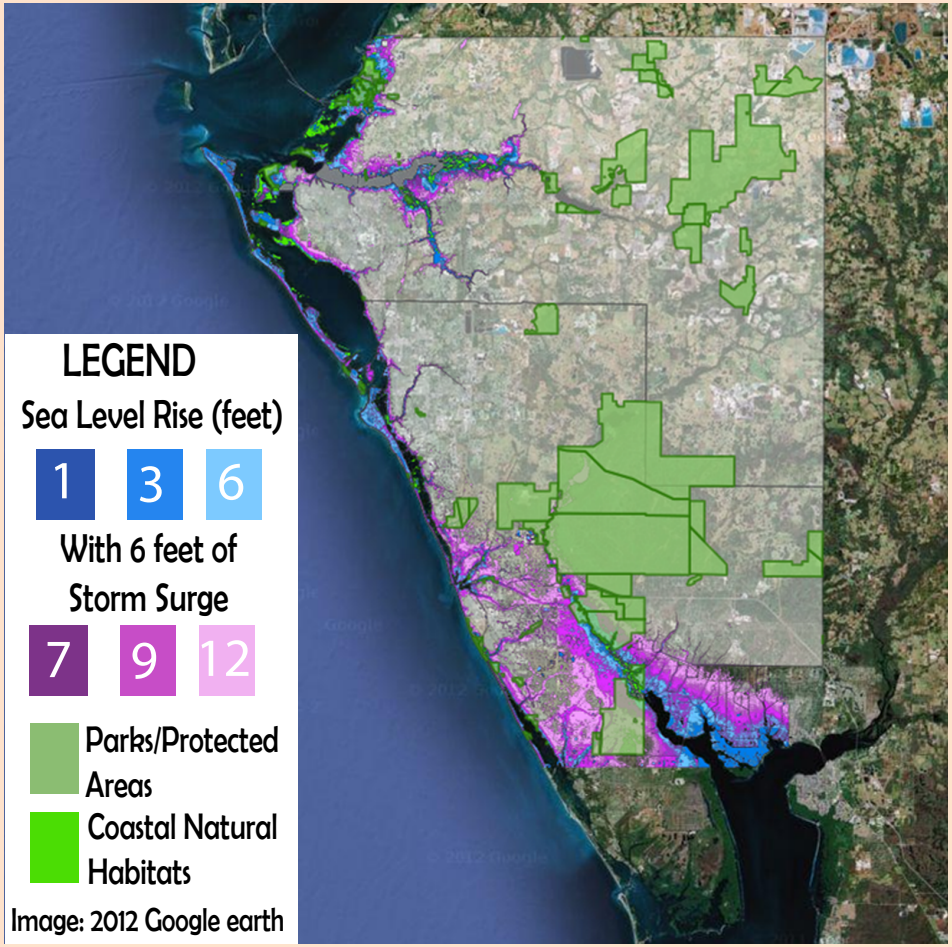
In addition, users can overlay the following:

- Parks and protected areas,
- Coastal natural habitats, and
- Major drainages and canals.

This tool will be useful for ecosystem managers when maintaining existing conservation areas, designing future restoration projects, or for prioritizing future land acquisition. In the example to the right, areas in blue show lands that will be vulnerable to a one-, three- and six-foot rise in sea level; purple and pink show the addition of six feet of storm surge. The barrier islands, as well as the major tributaries to Sarasota Bay, are especially vulnerable. In locations with parks and protected areas, these habitats may be able to migrate upslope, however, lands adjacent to urban development may be impacted.

The SLR Viewer can be accessed at: http://sarasotabay.org/slr-web-map/

Contact: sara@sarasotabay.org



An example output from the sea level rise viewer. Sarasota County is shaded in white; natural areas are shown in green. Source: SBEP

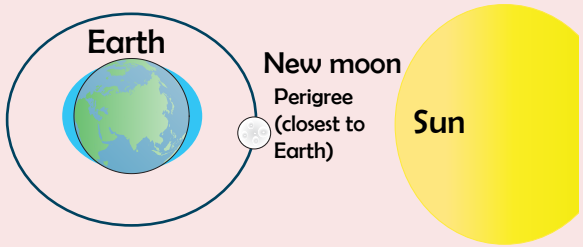
King Tide Photo Initiative Engages Community "Tide Watchers" in Florida

Sarasota Bay Estuary Program and Tampa Bay Estuary Program

Outreach

The Sarasota Bay and Tampa Bay Estuary Programs partnered on an outreach effort to help citizens visualize what sea level rise may look like in their communities and their own backyards. The project, called the "King Tide Photo Initiative," is modeled after a successful program that was started in eastern Australia. It encourages citizens to take pictures of areas within their watershed during a low tide event and then, again, during a King tide to document the differences in water levels.

King tides are the highest tide of the year. They occur when the moon and sun align on one side of the Earth and their gravitational forces combine to pull on the Earth's oceans, creating the highest high tides. They typically occur in the spring when the moon's highest annual tidal effects are realized. While these tides are completely natural occurrences, they provide a sneak peak of what the landscape may look like in coming years as the sea level rises.



Source: adapted from NASA; graphic not to scale

Sarasota Bay and Tampa Bay programs recruited "Tide Watchers" in 2012 to photograph coastlines, flooded roads, pipes, and ponds - anything that may be affected by rising waters during a King tide event and potentially in the future. Outreach staff primarily used social media outlets to reach community members and to share results.

Citizens were asked to capture the same location during the low and King tides and record the time the photos were taken. The initiative was well-received and the programs' Community Advisory Committees selected the winning entries. Photos were also exhibited at government offices and businesses throughout southwest Florida as part of "Chasing the Waves: The King Tide Photo Exhibit" to raise awareness about the effects of sea level rise on shorelines, structures, and communities.

Photos were added to a Flickr page: http://www.flickr.com/groups/1692657@N23
For more information, at SBEP, contact: sara@sarasotabay.org At TBEP, contact: misty@tbep.org

Low Tide Event **King Tide Event**

The photos above show a tidal area in Lido Key, part of the Sarasota Bay watershed. They were taken by Christine Sciarrino. The images below were taken by Larry Stults of Siesta Key in Sarasota Bay and were awarded 1st place in the photo contest.

Low Tide Event

King Tide Event

Climate Change Will Impact Critical Coastal Habitats in Tampa Bay, Florida

Tampa Bay Estuary Program

Tampa Bay is Florida's largest open-water estuary at approximately 400 square miles. Although more than 2.5 million people live within its 2,600 square mile watershed, it continues to support a diverse population of estuarine flora and fauna.

The Tampa Bay Estuary Program (TBEP) has developed a Habitat Master Plan to set restoration and protection goals for critical coastal habitats such as seagrass, mangroves, salt marsh, and salt barrens, using a novel management concept called "Restore the Balance." Recognizing that some habitats cannot be regained due to development or dredging, the scientific community in Tampa Bay recommended that estuarine habitats be restored in a similar ratio to what existed in the 1950s prior to extensive development in the watershed. This approach will ensure that there are adequate habitats for all estuarine fish and wildlife species throughout their life cycles, including juvenile stages.

A salt barren habitat is shown in the foreground with marsh and mangroves in the background. Photo: Lindsay Cross

Managers prioritize restoration of salt marsh and salt barren habitats

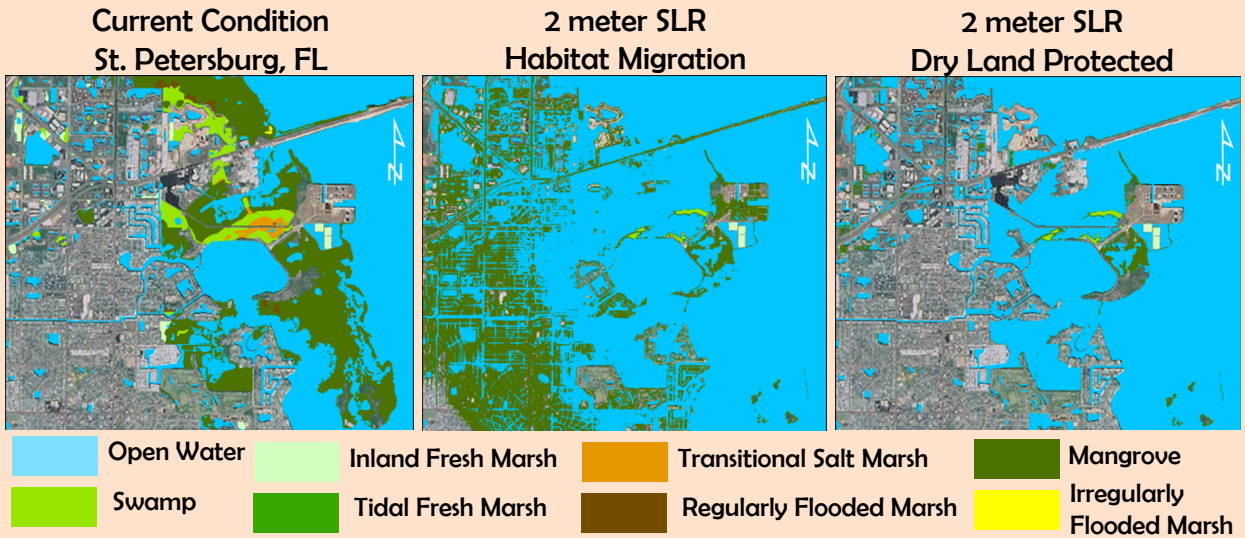
TBEP and partners assess the coverage of estuarine habitats every 10 years to determine where gains and losses have occurred. They then develop quantitative restoration goals for each habitat type to restore the historic proportions. In recent decades, salt marsh and salt barren habitats have been disproportionately lost, whereas mangroves have exceeded their historic ratios. Environmental managers are encouraged to prioritize restoration of salt marsh and salt barrens, while protecting the existing mangrove acreage. Since the 1990s, there has been an emphasis on habitat restoration using the "Restore the Balance" approach, which has led to an overall increase in critical coastal habitats.

Modeling illustrates impacts to habitats

Scientists at TBEP used models to visually determine how sea level rise may impact coastal habitats in the Tampa Bay region in year 2100. To do this, scientists used:

- Land use/land cover and wetlands data,
- Digital elevation models,
- Information on dikes and other water control structures, and
- Sea level rise scenarios using the Sea Level Affecting Marshes Model (SLAMM, 2013). Ten scenarios ranged from 40 cm (~1.3 feet) to 2 meters (~6.6 feet).

The maps below show the current coastal habitats in northeastern St. Petersburg (left). The other graphics illustrate which habitats may exist with 2 meter (~6.6 feet) of sea level rise (SLR) either allowing migration of habitats into developed areas (center) or protecting dry land and infrastructure (right). Source: Ed Sherwood



Habitats will be impacted regardless of adaptation strategies

Modelers applied two opposing land management or adaptation strategies to the modeling effort to examine how they may affect habitats differently. Scenarios were:

- Protect currently developed dry land, or
- Allow coastal habitats to migrate upslope, possibly into areas that are currently developed.

Regardless of the land management strategy, the total coverage of critical coastal habitats in the Tampa Bay region will decrease with sea level rise. The largest losses are expected for coastal freshwater marshes, salt marshes, and salt barrens. In each scenario, the proportion of mangroves will increase, however, the total coverage of mangroves will only increase if habitats are allowed to migrate.

Community volunteers plant salt marsh grasses, which are expected to be impacted by sea level rise in Tampa Bay. Photo: Lindsay Cross

Restoration strategies for critical coastal habitats may change with sea level rise

Current habitat management strategies may have to be adapted to consider the impacts of climate change and continued development within the watershed. In particular, the "Restore the Balance" approach may no longer be feasible, especially if Tampa Bay is moving towards a mangrove-dominated system. Managers need to discuss where restoration efforts will be the most beneficial and will have long-term success.

Suggested adaptive management strategies for the Tampa Bay region are to:

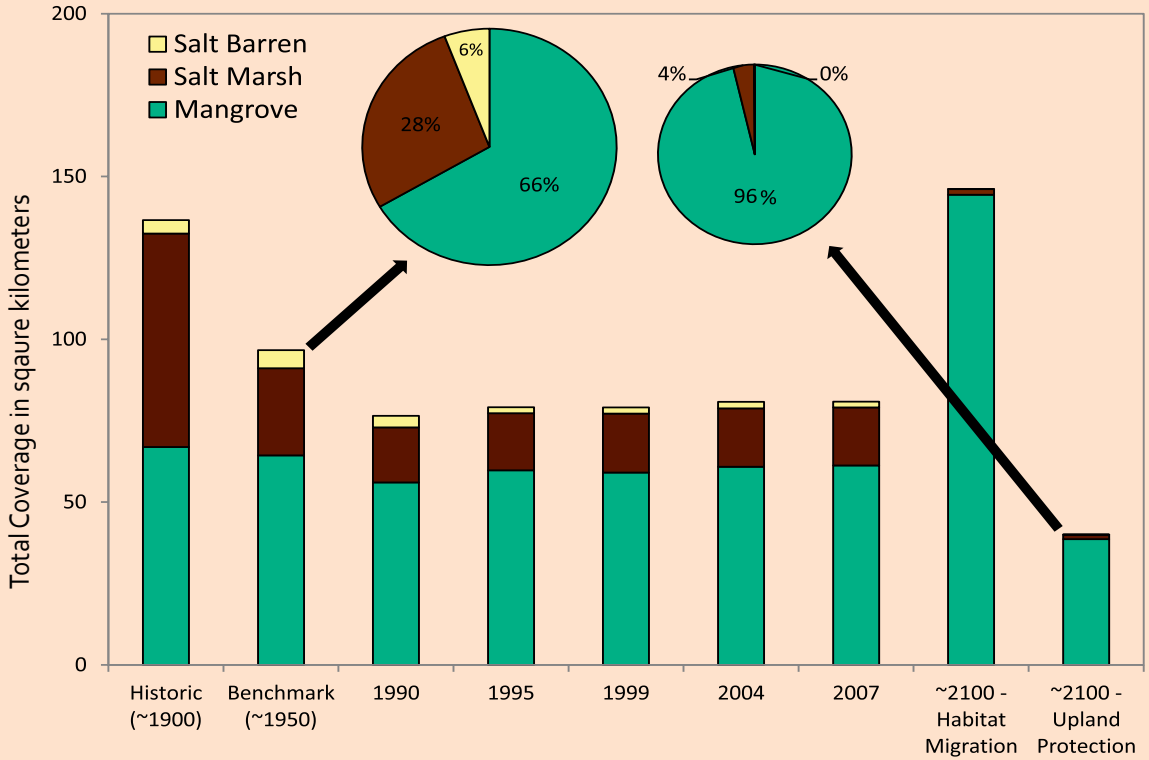
- Focus restoration on the creation of habitat mosaics that may be more resilient to future changes in sea level or other climate change impacts, and
- Protect upslope "refugia" areas to allow sensitive habitat types such as salt barrens to migrate upslope.

The Tampa Bay community will continue to work collaboratively to ensure the protection of critical coastal habitats, although the strategies used today may need to be modified to address future impacts.

Report available at:http://tbeptech.org/TBEP_TECH_PUBS/2012/TBEP_03_12_Updated_Vulnerability_Assessment_082012.pdf

Contact: esherwood@tbep.org

Coastal Habitat Coverage Mapped in Tampa Bay and Modeled in 2100 with 2 meters Sea Leve Rise



Total coverage of coastal habitats mapped in Tampa Bay decreased between 1950 and 1990 but increased between 1990 and 2007. The ratio of habitats has shifted towards a larger percentage of mangroves. Sea level rise of 2 meters would result in a total loss of salt barren habitats under both management scenarios. Source: Ed Sherwood

Habitat Mosaics Improve Climate Change Resiliency at Fred and Idah Schultz Preserve, Florida

Tampa Bay Estuary Program

Habitat restoration in the Tampa Bay area has evolved from small (<0.5 acre), single-species marsh plantings to large (>1,000 acres) projects that restore multiple species and habitat types. The science behind ecosystem restoration has improved, leading to more complex and beneficial projects.

An early restoration project involving one marsh grass species at a small site. Photo: Nanette O'Hara

A sophisticated restoration at Cockroach Bay using the habitat mosaic approach. Photo: Lindsay Cross

Habitat mosaics provide ecosystem benefits

A restoration paradigm used in Tampa Bay is the "habitat mosaic" approach. It incorporates a diversity of habitat types and functions, as opposed to a single habitat type. Benefits of this include:

- Habitat complexity,
- Support for a greater number of species,
- Variety of salinities and salinity gradients,
- Potential areas for habitat migration, and
- Potential stormwater polishing.

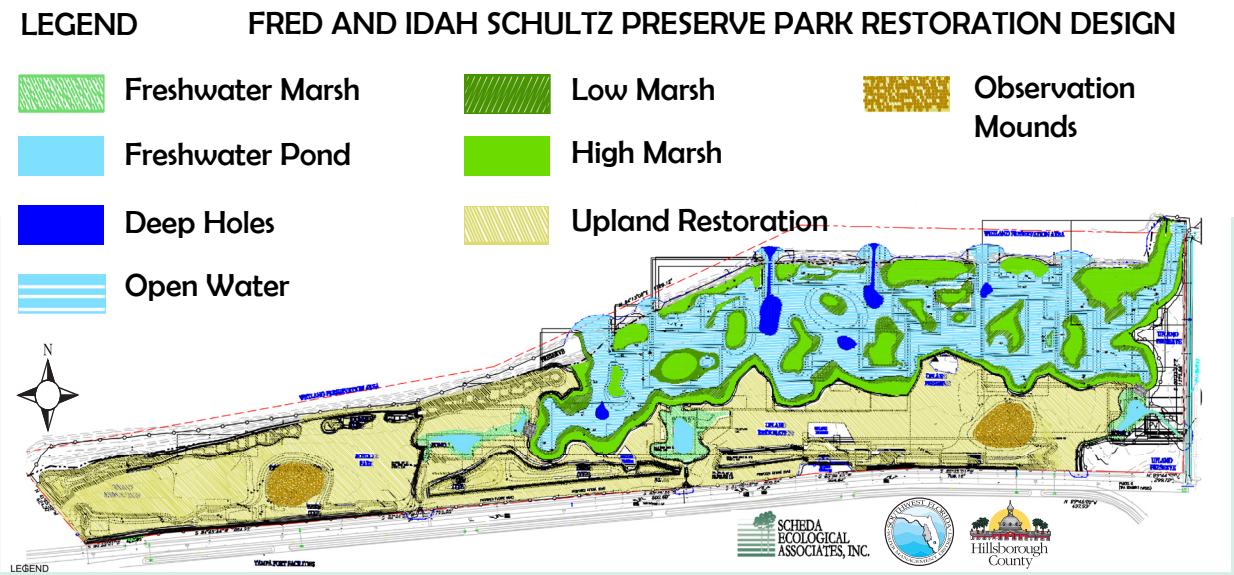
The habitat mosaic approach has been used in the majority of projects within the Tampa Bay watershed and has become an effective model for environmental restoration. This approach was applied when constructing the Fred and Idah Schultz Preserve.

Site has history of environmental degradation

The Fred and Idah Schultz (Schultz) Preserve lies on a peninsula on the eastern side of Tampa Bay. The 300-acre peninsula was created in the 1960s and 70s by depositing dredged material onto seagrass beds, an island, tidal flats, oyster bars, mangroves, salt barrens, and coastal uplands. The dredging was conducted to create a shipping channel for a port facility that was never constructed. The site became infested with non-native plants and also became a site for illegal dumping and other harmful activities.

Despite its history, the site was attractive to environmental managers because of its proximity to other publicly-owned conservation areas, including the 700-acre Cockroach Bay Preserve. In 1995, the northern 120 acres, which would become the Schultz Preserve, were purchased by the Southwest Florida Water Management District - a regional water authority, and Hillsborough County's Environmental Lands Acquisition and Protection Program. The remaining and adjacent portions of the peninsula are owned by the Tampa Port Authority.

Source: Scheda Ecological Associates, Inc.



Design incorporates a suite of wetland and upland habitats

While some restoration projects create estuarine and freshwater wetlands by converting upland areas, this project included true "type-for-type" restoration. Because the area was historically estuarine, environmental managers had to remove deposited dredged sediments to create estuarine components and were even able to find and restore an historic island using historic aerial photographs.

The completed site contains a mixture of habitat types, including:

- 10 acres of freshwater marshes and ponds,
- 50 acres of estuarine habitat,
- Artificial reefs and an historic island,
- Transitional communities, and
- 60 acres of uplands.

Site attracts protected wildlife species

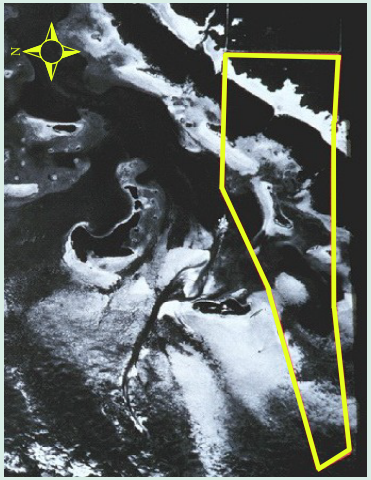
Various fish and wildlife species began recruiting to the site, even before construction was finished. Seagrass beds and oyster bars have naturally recruited to the area, providing a food and habitat source for many estuarine-dependent species. The mosaic approach provides habitats for a suite of estuarine species throughout their life cycle. Scientists have observed numerous protected species utilizing the preserve, including the endangered Peregrine falcon, American wood stork, West Indian manatee, American bald eagle, bottlenose dolphin, and roseate spoonbill.

Freshwater marshes polish stormwater from the surrounding upland areas and deliver the freshwater to the intertidal lagoon in a more natural way. This improves nursery functions in the lagoon and restores the natural hydrology and flow.

Gradual upland slopes provide potential for marsh and mangrove migration

Nearly half of the restored site was developed as upland habitat, which was planted with a mixture of pines, palms, oaks, and grasses. The area was contoured with gradual slopes to allow estuarine plants to migrate upslope with rising sea levels. The upland component was actually the most difficult restoration aspect because the soil material was dredged bay bottom. While most of the salt content had been reduced over the years, the sediment contained very little organic material, necessary for upland plant growth. Understanding that maintenance is an important component of any restoration project, a comprehensive management plan was developed to ensure the long-term success of the project and to document how the area changes over time.

Contact: bhenningsen@watermatters.org



The aerial photo on the left shows the site in 1938 prior to development of the peninsula. The middle photo shows the area prior to restoration and the photo on the right shows the completed project incorporating the habitat mosaics. Note the orientation of each is different. Photos: Hillsborough County (left), Aerial Innovations (middle, right)

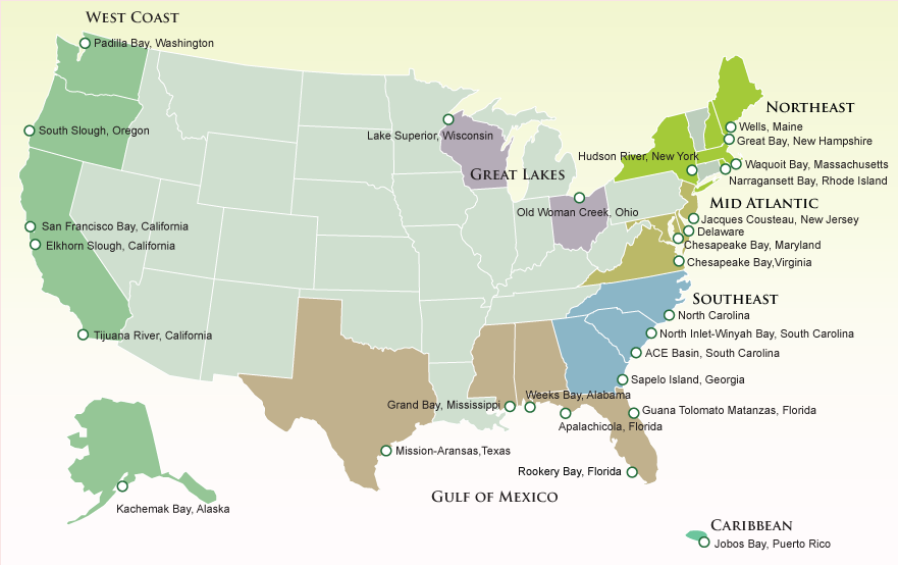
National Estuarine Research Reserves

The National Estuarine Research Reserve (NERR) System is a network of 28 sites, each representing areas with high biodiversity throughout different biogeographic regions of the United States. The system was established by the Coastal Zone Management Act of 1972 and is a partnership of the National Oceanic and Atmospheric Administration (NOAA) and coastal states. NOAA provides funding, guidance, and technical assistance with on-site management by a lead state agency or university, and input from local partners.

The Reserve System mission is to practice and promote the stewardship of coasts and estuaries through innovative research, education, and training using a place-based system of protected areas.

Each NERR participates in the System-Wide Monitoring Program (SWMP) that helps address specific coastal management needs and guide national, regional, and local research efforts that promote the protection and conservation of estuarine habitats.

Reserve staff also work with local communities and regional groups to address natural resource and management issues such as non-point source pollution, habitat restoration, and invasive species control.



NERRs are found in most coastal states throughout the United States; five Reserves are located along the Gulf of Mexico. Source: NERRs. Top-right and right: citizens and scientists participate in research and monitoring programs. Photos: Lindsay Cross

NERRs are living laboratories

The NERRs are protected for long-term research, water quality monitoring, education, and coastal stewardship. They are platforms for long-term research and monitoring and serve as "living laboratories." The goals of the system's research and monitoring program include:

- Ensuring a stable environment for research through long-term protection of Reserve resources;
- Addressing coastal management issues through coordinated estuarine research within the System; and
- Collecting information necessary for improved understanding and management of estuarine areas, and making the information available to stakeholders.

For more information visit: www.nerrs.noaa.gov

Addressing Reserve Resiliency through Disaster Response Planning

Gulf Coast National Estuarine Research Reserves

The National Estuarine Research Reserves are often located in environmentally sensitive coastal areas and are exposed to many of the same hazards that threaten urban, suburban, and rural areas. The Reserves are responsible for the protection of commercial and recreational fishing habitat, emergent vegetation, and critical habitat that supports fish and wildlife species. As non-regulatory entities, the Reserves do not implement law enforcement, fire suppression, emergency medical or other disaster response actions that are typical of cities, counties, and states. Therefore, the Reserves are largely dependent upon the established disaster response plans of the environmental, public health, and safety agencies within their watersheds, or of adjacent communities.

The National Oceanic and Atmospheric Administration (NOAA), through its Gulf of Mexico Disaster Response Center, is conducting assessments at NERRs throughout the Gulf of Mexico to determine the environmental impacts and response efforts after natural and man-made disasters such as hurricanes or the Deepwater Horizon oil spill. This information will be incorporated into a disaster response plan that will outline how each Reserve can be better prepared.

Stakeholder workshop first step towards plan for Mission-Aransas NERR

The Mission-Aransas NERR in Texas has been engaged in the development of a disaster response and action plan to reduce the impact of hazards to the Reserve's habitats. A stakeholder workshop was held in June 2012 to gather input from agencies tasked with responding to natural resource-related disasters, including US Fish and Wildlife Service, US Coast Guard, and Texas Parks and Wildlife Department. Participants discussed:

- Existing disaster response plans,
- Agencies and government roles and responsibilities, and
- The role that the Reserve would play in the event of a disaster.

Workshop participants review existing emergency management protocols and discuss components of the disaster response plan for Mission-Aransas Reserve. The Mission-Aransas River, shown at the right, provides critical habitats that could be affected by a natural or man-made disaster. Photos: Mission-Aransas NERR

The workshop provided stakeholders with the opportunity to become familiar with the capabilities of the Reserve to assist during a disaster, including access to physical assets such as boats, personnel, and volunteers; sampling and testing capabilities; and detailed knowledge of the Reserve and its natural resources.

The Mission-Aransas NERR disaster response plan will incorporate information gathered at the stakeholder consultation workshop to outline hazards to its natural resources, current plans in place to guide disaster response, and the responsible entities and command structure. The plan will be periodically updated to reflect any changes in emergency management structure or disaster response capabilities.

Contact: Kristin.Hicks@austin.utexas.edu

Sentinel Sites Monitoring Program Will Detect Climate Change Impacts at NERRs

Gulf Coast National Estuarine Research Reserves

The National Estuarine Research Reserves (NERRs), located along all three coasts of the continental United States, Alaska and Puerto Rico, are at the front line of climate change impacts such as sea level rise. Through the Research and Monitoring program, the NERRs are able to provide the platform and resources necessary for targeted climate research and monitoring activities. Using locally-relevant data, NERR staff can translate climate science for decision makers and educate coastal residents through the Education and Coastal Training programs. By establishing locations within the Reserves as "Sentinel Sites," they are taking the first steps toward an organized, systematic monitoring program that will use sea level measurements, water quality data, and inundation changes to understand changes in coastal vegetation communities.

The implementation plan for the NERR's Sentinel Sites defines these sites as "areas in coastal and marine environments that have the operational capacity for intensive study and sustained observations to detect and understand changes in the ecosystems they represent. Observational data are collected with instruments at measurement stations (platforms and sensors) within each site, providing information and data that can be synthesized to provide an understanding of the ecological status and trends in physical and biological variables of interest."

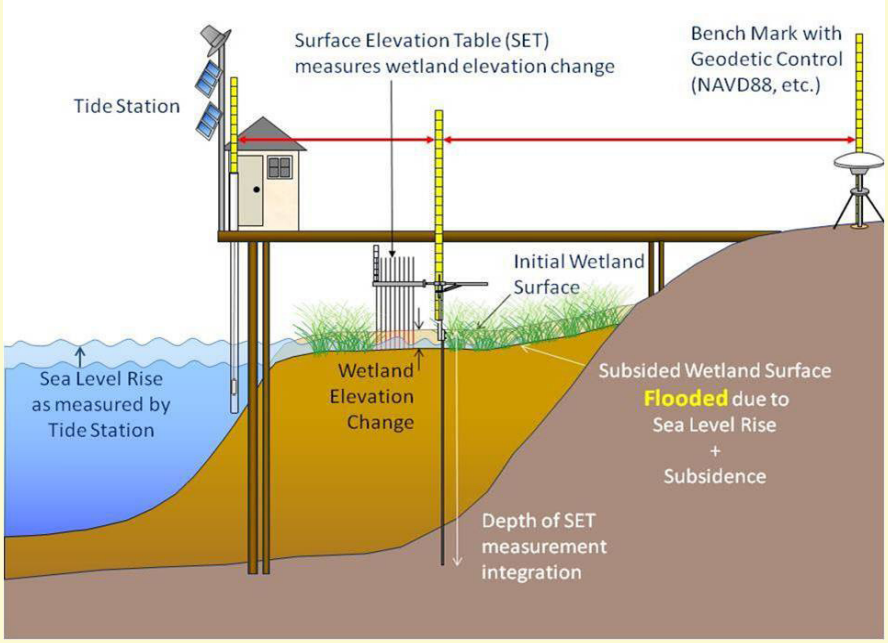
Program builds upon existing monitoring

The Research Reserves already serve as Sentinel Sites for changes in water quality through the System-Wide Monitoring Program (SWMP). Each NERR maintains continuously-recording data loggers at four locations within their estuary.

Each logger records parameters, including temperature, salinity, dissolved oxygen, pH, turbidity, and depth, every 15 minutes. These data are uploaded to the NERR Centralized Data Management Office (CDMO), go through several quality assurance checks and are made available to the public online. Because strict data collection and quality assurance techniques are in place, variability within years and comparisons between the NERRs can be made.

Changing water levels will affect habitats

Gulf Coast NERRs, which have been participating in the SWMP, will now be able to link their water quality data to water level (an exact elevation), so that changes in water quality can be related to changes in factors such as river flow, sea level, and tidal inundation. Coastal vegetation communities are predicted to change dramatically in response to sea level rise. This may be caused by several factors including the rate of sea level rise, changes in the frequency and duration of inundation, total suspended solids available, subsidence (land sinking), erosion, and accretion.



Example of a Sentinel Sites Geospatial Infrastructure monitoring station designed to study the impacts of changing water levels on vegetation. Source: NERR

Sophisticated instruments will measure water and surface elevations

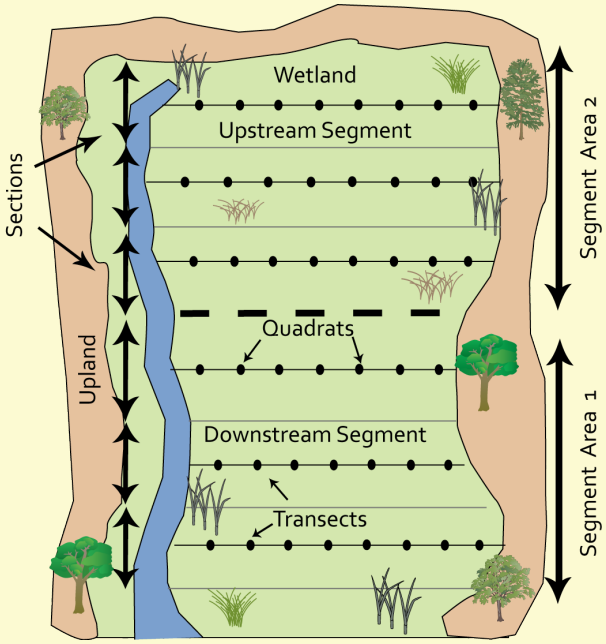
A key component is measuring how water and land elevations change due to factors such as erosion, accretion, and shallow subsidence. These can be measured using a sophisticated device called a Surface Elevation Table (SET). The SET utilizes a rod, which is driven into the ground, and an arm that can rotate 360 degrees. The exact elevation of the rod is determined through leveling or Global Positioning Systems (GPS) measurements. Multiple measurements in four directions (north, east, south, and west) are gathered to detect small changes, sometimes on the order of millimeters, in the adjacent habitat surfaces.

A researcher collects elevation measurements at a sentinel site using the SET. Photo: Apalachicola NERR

Monitoring program will include fixed sites and transects through wetland habitats

Each NERR will install and monitor SETs at appropriate locations throughout its estuary which contain important natural communities and are representative of the habitats within the NERR. In Apalachicola NERR, for example, six sites have been located in the fresh/brackish marshes along the lower portion of the Apalachicola River, six within brackish marshes within the Bay, and eight within salt marshes along a barrier island, which may be especially susceptible to gaining or losing sediments.

Vegetation monitoring transects will also be established to characterize the types of plants found in these areas and to record changes in these species over time, based on changes in inundation. Porewater monitoring wells will be installed to measure the salinity of the soil - an indicator of salt water intrusion.



An example of a wetland sampling design. Data is collected at quadrats located along linear transects within a marsh system. The study area can be divided into sections and segments. Source: Adapted from Moore 2009.

Accurate baseline data is critical

Determining the elevation of all research components and tying them together into a local vertical control network is one of the most difficult and expensive components of this program - but necessary for its success. NERRs have partnered with agencies such as the National Geodetic Survey to measure accurate elevations using leveling or GPS technology to survey sites.

Partnerships provide funding and support

Much of the funding for this program is through the Gulf of Mexico Alliance (GOMA). Within individual NERRs, additional state or local funding may help to support the program. In Apalachicola NERR, partners include Florida Department of Environmental Protection's Bureau of Survey and Mapping, and NOAA's National Geodetic Survey.

This project allows NERRs to expand their water quality programs by adding water level measurements to water quality sites, measuring erosion and accretion in vital marsh areas, and recording changes in marsh community composition. Data collected from the Sentinel Site effort will be used to model the impacts of different rates of sea level rise. This work will allow resource managers to target areas for conservation, identify lands for acquisition to allow natural communities to migrate, and to predict the success of restoration efforts.

Contact: Jennifer.Harper@dep.state.fl.us

Ecological Effects of Sea Level Rise in the Northern Gulf of Mexico Research Reserves

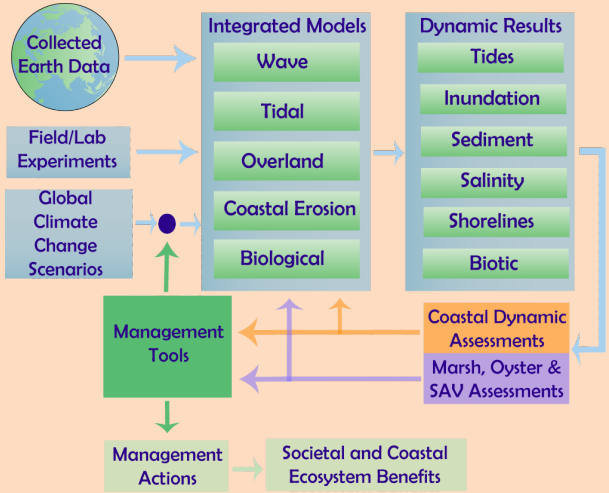
Apalachicola, Grand Bay, and Weeks Bay National Estuarine Research Reserves

The northern Gulf of Mexico benefits from a wealth of natural resources and an economy dependent on healthy coastal environments. The combined impacts of rising sea level and tropical storms on the northern Gulf's coastal areas will be dramatic and represent a significant threat to coastal communities. Low-lying coastal areas, including barrier islands, can be expected to experience increased levels of flooding, accelerated erosion, loss of wetlands and low-lying terrestrial ecosystems, and seawater intrusion into freshwater sources. These impacts may also affect key offshore resources such as oyster reefs and submerged aquatic vegetation.

A multidisciplinary team, led by the University of Central Florida, will use field observations collected at Apalachicola, Grand Bay, and Weeks Bay NERRs, shown below, to examine ecological effects of sea level rise in the northern Gulf of Mexico.

Field observations will inform models

The project will integrate field observations and laboratory experiments into a suite of models that will forecast how factors such as circulation, runoff, salinity, and shoreline erosion may impact habitats such as marsh, seagrass, and oysters. The process chart, shown below, will provide coastal managers with the knowledge and tools to prepare for the impacts of tides and storm surge from rising sea levels with increased certainty in scale, timing, and local detail.



Key findings from various sea level rise scenarios will include:

- New tidal boundaries,
- Sediment loadings to estuaries,
- Estimates of marsh dynamics,
- Habitat changes, and
- Sensitivities of oysters and seagrasses.

Results will improve habitat management

Improving forecasts of dynamic ecosystem responses to sea level rise and storms will enable coastal managers to more effectively assess alternative management strategies for mitigating future ecological and societal impacts. Results will facilitate the development of:

- Priorities for reducing risk to coastlines;
- Shoreline restoration, breakwater, and coastal construction guidelines;
- Water resource impact assessments; and
- Resource sustainability in project planning.

Information from projects, such as experiments growing marsh grasses (left) and oysters (below), will help inform scientists about potential impacts to these habitats from sea level rise. Photos: Scott Hagen

Contact: Scott.Hagen@ucf.edu or David.Kidwell@noaa.gov

Habitat Mapping and Change Plan for Apalachicola NERR, Florida

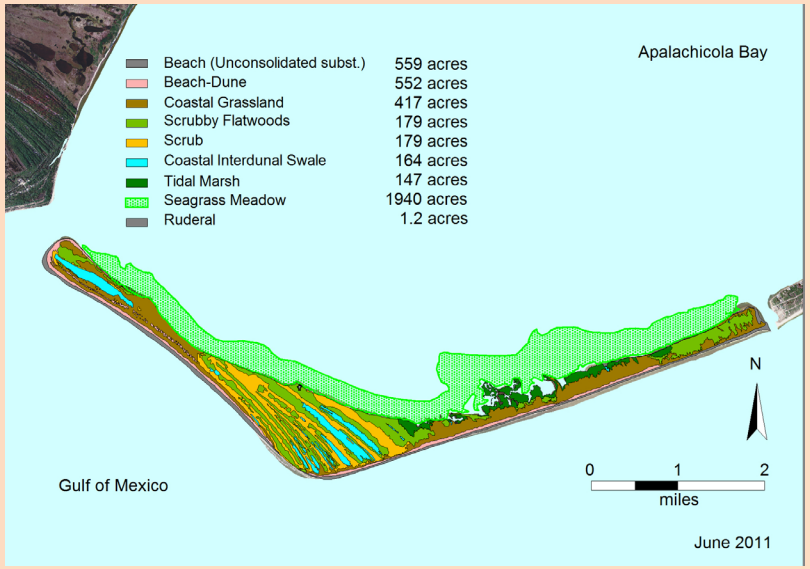
Apalachicola National Estuarine Research Reserve

The Apalachicola National Estuarine Research Reserve (ANERR) is the second largest Reserve in the system at nearly 235,000 acres. The Reserve includes the bay and its associated tidal creeks, marshes and bayous, portions of the Apalachicola River and its floodplain and upland areas, and portions of offshore barrier islands. The Apalachicola River basin is part of the larger Apalachicola-Chattahoochee-Flint River system which drains an area of approximately 19,600 square miles and includes portions of Georgia, Alabama, and Florida. The Reserve contains diverse habitats that support numerous wildlife species, including rare and endangered plants and animals.

The Apalachicola-Chattahoochee-Flint Basin drains into Apalachicola Bay, part of Apalachicola NERR. Source: Pfly

Habitat maps will provide a baseline to evaluate climate change impacts

This project aims to map the current extent and location of natural communities and habitats within the ANERR boundary. The completed habitat map will be used to track and evaluate changes over time in coastal and estuarine habitats and will provide a better understanding of how those changes relate to anthropogenic influences from the watershed and environmental stressors related to climate change.



Cape St. George (aka Little George Island) is a barrier island consisting of approximately 2,300 acres. The island is a coastal dune/dune flat/washover barrier formation. In addition to providing habitat, it is a "first line of defense" for the coastal mainland against destructive hurricanes. Credit: ANERR

Apalachicola River and its watershed contains a mix of fresh and estuarine wetland species. Photo: ANERR

The river is an important economic asset which helps to support a vibrant commercial fish and shellfish industry, as well as recreational activities. Photo: Apalachicolabay.org

Mapping the lands on a 5-year rotation will allow researchers, local communities, and governments to track changes in the natural resources due to land use change and/or natural events such as storm erosion or sea level change. This information will aid Reserve managers in developing appropriate resiliency and adaptation strategies for the mix of habitats within the Reserve.

Contact: Kim.Wren@dep.state.fl.us

Coastal Communities Engage in Climate Adaptation Training in Northern Gulf of Mexico

Grand Bay National Estuarine Research Reserve and Weeks Bay National Estuarine Research Reserve

The Grand Bay and Weeks Bay National Estuarine Research Reserves (GDBNERR, WBNERR) have partnered on several initiatives to engage coastal communities and resource managers in climate change adaptation and vulnerability training.

Representatives from regional, town, and county agencies; non-profit groups; and consultants from coastal communities in Mississippi and Alabama attended a three-day workshop, taught by NOAA's Coastal Services Center, to prepare for future impacts associated with climate change. Stakeholders learned how climate change may impact their communities, how to identify key elements of a vulnerability assessment, and how to use this information to select and prioritize adaptation efforts. They also evaluated strengths and weaknesses of adaptation measures and discussed ways to more effectively communicate with their communities.

Fishing is an important commercial and recreational activity in many coastal communities. Photo: Cheryl Empey

Measures to cope with climate change similar to those for storm preparation

Participants learned from local experts and other coastal communities that have begun adaptation efforts. Staff from the City of Biloxi shared recent efforts focused on climate adaptation, including educating the community about climate change and revising their hazard mitigation plan to address climate change impacts.

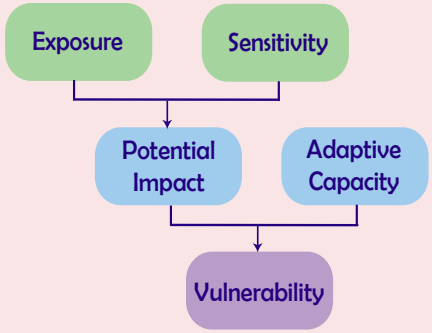
Participants learned about the challenges of climate adaptation from an activity called "Protect the Egg" in which they had to "buy" materials using limited resources to protect their egg, which would be dropped from an unknown height. Photo: Larissa Graham

Participants were pleased to learn that climate adaptation could be incorporated into existing programs and that many were similar to what they were already doing to prepare for storms.

Resource managers learn assessment tools

In an interactive course modeled after the publication "Scanning the Conservation Horizon - A Guide to Climate Change Vulnerability Assessment," GDBNERR and WBNERR partnered with National Coastal Training Center and US Fish and Wildlife Service to provide climate change vulnerability assessment training to conservation and resource managers. It focused on how to determine which species or habitats are most vulnerable when setting conservation priorities, including how to:

- Understand vulnerability assessments in a broader context of adaptation planning;
- Evaluate different factors influencing vulnerability and how they can affect the outcome of vulnerability assessments;
- Identify and evaluate approaches for conducting a vulnerability assessment and choose among different options;
- Design a vulnerability assessment;
- Evaluate and interpret results of the assessments and develop next steps;
- Communicate the process, methods, and results to others; and
- Develop elements of a vulnerability assessment workplan/statement of work.



Components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity. Source: NWF

For information on these coastal training opportunities, contact: Larissa.Graham@dmr.ms.gov at GDBNERR or Michael.Shelton@dcnr.alabama.gov at WBNERR.

Balancing Freshwater Needs in a Changing Environment in Mission-Aransas, Texas

Mission-Aransas National Estuarine Research Reserve

Planning

MISSION ★ ARANSAS
NATIONAL ESTUARINE RESEARCH RESERVE

The estuaries of central Texas are vital to the state's economy, supporting multibillion dollar recreational and commercial fisheries, as well as a growing tourist industry. Freshwater is a critical component of these estuaries, creating a salinity gradient important to estuary dependent organisms, such as fish, shrimp, oysters, and crabs. However, growing water demand by industry, agriculture, and municipalities, combined with land use change and shifting climate patterns, has greatly reduced the amount of freshwater that estuaries along the central Texas coast receive.

Mission-Aransas National Estuarine Research Reserve (MANERR) is leading a research team with University of Texas and Texas A&M University to develop freshwater inflow recommendations for the Guadalupe-San Antonio and Mission-Aransas estuaries. Specifically, the project is addressing the effects of land use and climate change on freshwater inflows, circulation of freshwater between estuaries, and effects of freshwater on commercially and biologically important marine organisms. The effort will also incorporate the priorities of the growing communities that depend on the estuaries.

Stakeholders provide valuable input

One of the primary project objectives is to work with stakeholders to mutually define priority information for input into decision support tools (DSTs) that will be used to examine the effect of land use and climate change on the volume of freshwater inflow.

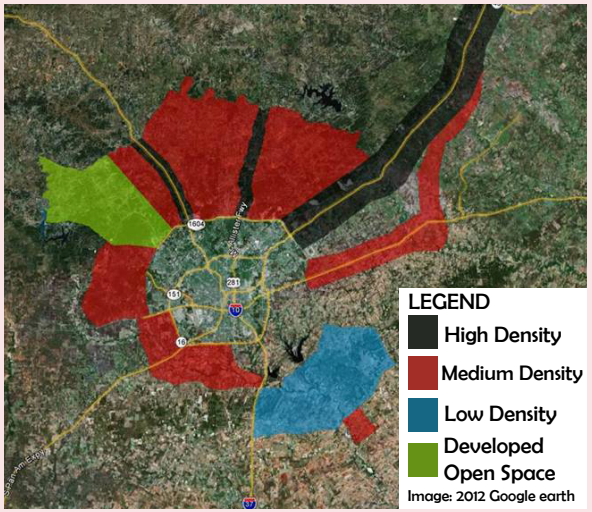
Stakeholders discuss future land use scenarios using interactive methods. Photo: MANERR

The team is using collaborative methods to bring together local experts, such as land use planners, water authorities, and resource managers, to gather and prioritize information (e.g., population projections, future urban growth areas, and conservation priorities) for development of products and scenarios to support decision making. Ultimately, the team will use this knowledge to create a system dynamics model of the Mission-Aransas Estuary that stakeholders can use to refine future inflow recommendations for this region.

Examining the effects of land use and climate change on freshwater inflow

The toolkit will be tailored to examine changes in runoff and water usage for multiple watershed land use and climate scenarios at a variety of scales, including the watershed, and using a variety of data sources. Although the DSTs rely on a number of assumptions, they are beneficial for evaluating and comparing several scenarios in a quick and efficient manner. The toolkit will integrate three DSTs that are all extensions to ESRI's ArcGIS platform, including CommunityViz, N-SPECT, and Vista computer software programs.

Contact: Kiersten.madden@utexas.du



Stakeholder predictions of likely future land use and population growth in the Central Texas region by the year 2060. Source: MANERR

Understanding Freshwater to Maintain a Healthy Rookery Bay Estuary, Florida

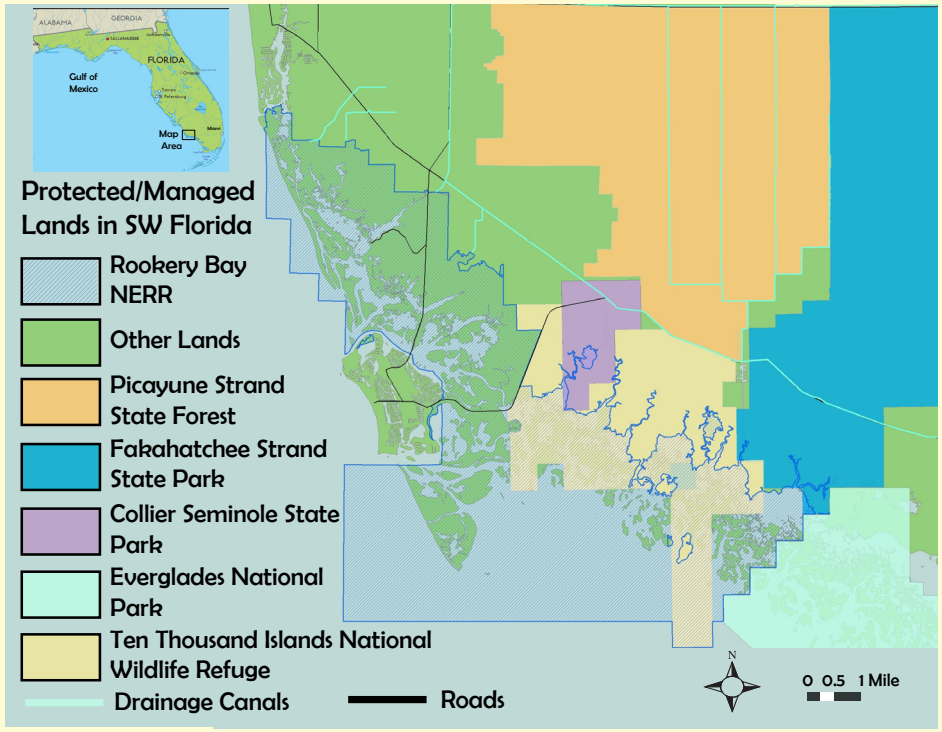
Rookery Bay National Estuarine Research Reserve

A multi-disciplinary team led by Florida's Rookery Bay National Estuarine Research Reserve (RBNERR) has received an $815,000 grant for a three-year project to help local communities manage freshwater flows in the Henderson Creek watershed.

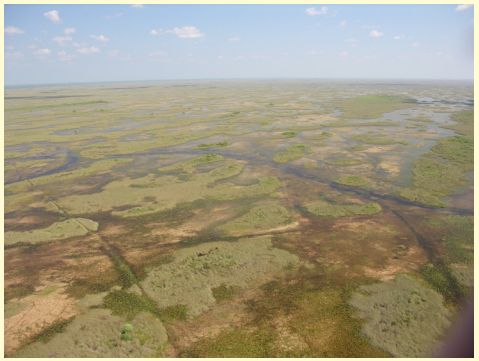
One of the few pristine, mangrove-forested estuaries in the US, the Rookery Bay estuary is a nursery for commercial and recreational fisheries like blue crab, stone crab, snook, tarpon, and snapper. Each year, thousands of tourists are drawn to its vast expanses of natural space to fish, swim, kayak, and experience manatees, dolphins, and coastal birds in their native surroundings.

Restoration of the Everglades may benefit Rookery Bay

A large portion of south Florida is protected as state or federal areas. Rookery Bay NERR encompasses portions of these managed and conservation lands such as the Ten Thousand Islands National Wildlife Refuge. Efforts are underway to restore habitats through the Comprehensive Everglades Restoration Project (CERP). While this extends beyond the RBNERR boundary, restoration of habitats and hydrology as part of CERP may lead to water quality and habitat improvements in Rookery Bay.



Southwestern Florida contains many conservation and managed lands, including Rookery Bay NERR, Picayune Strand State Forest, and Everglades National Park.Source: RBNERR



Water flow within the Everglades has been altered by drainage canals which criss-cross the marsh habitat. Photo: US Army Corps of Engineers

Freshwater is critical for healthy estuaries

The health of the Rookery Bay estuary and its wildlife depend on seasonally-appropriate flows of freshwater that range from nearly 134 million cubic feet (more than 1 billion gallons) per day in the wet season to none in the dry season. These freshwater flows also sustain nearby communities in Collier County and Marco Island.

The Ten Thousand Islands (background) and the developed community of Marco Island (foreground) are within the RBNERR area. Photo: RBNERR

Population growth and saltwater intrusion into community and government wells are placing further stress on available freshwater.

Sea level rise will likely exacerbate these problems, causing brackish or saltwater to seep into freshwater areas. Compounding the situation are the highly-managed water control structures and canals that were built to control flooding in the area, but also disrupt the natural flow of freshwater that is necessary for estuarine health.

Above: An example of a large drainage canal in southwestern Florida. These structures have altered the natural delivery of freshwater to downstream areas such as Rookery Bay. Photo: US Geological Survey

Below: An aerial view of a weir structure on Henderson Creek which controls the quantity and timing of water released downstream. Photo: RBNERR

Computer models will show historic and current water flows

The project will include various technical components such as water quality and quantity monitoring at pumping stations located along Henderson Creek. This information is being integrated into computer models that can illustrate how water flowed in the past, prior to extensive draining and constructed canals, compared to how it flows currently.

Understanding how water is flowing within the system can help scientists better understand current conditions and where improvements can be made.

Above: A scientist collects water quality information along Henderson Creek. Right: Henderson Creek. Photos: RBNERR

Project will address multiple water users

The water flow information, as well as water quality data, will be incorporated into a collaborative framework that stakeholders can use to make decisions about water issues in the future. The project team includes an advisory group composed of hydrological engineers, social researchers, resource managers, and community stakeholders.

Decision-making tool will aid community

Balancing the water needs of people and the natural systems on which they depend for jobs and recreation is becoming increasingly challenging as communities grow and sea levels rise in southwest Florida. This project aims to address this challenge by improving the knowledge of the freshwater flows necessary to maintain a healthy Rookery Bay estuary and understanding the attitudes of water users. This will inform future educational efforts and will result in a collaborative decision-making tool that will assist the community in making better decisions related to water use and allocation.

Contact: Tabitha.Stadler@dep.state.fl.us

Research to Address Effects of Everglades Restoration on Sharks in Rookery Bay, Florida

Rookery Bay National Estuarine Research Reserve

In the 1960s, a large residential neighborhood with a network of roads and 58 miles of canals was created just north of the Ten Thousand Islands, part of the Everglades ecosystem in southern Florida. The project, originally called Golden Gate Estates, was later abandoned; however, the failed development permanently altered the natural sheet-flow of freshwater to the estuarine bays of the Ten Thousand Islands. The State of Florida purchased the land and now maintains it as part of the Picayune Strand State Forest.

Too much (or too little) freshwater can be detrimental to estuarine systems

The constructed canal system directed freshwater runoff down one central canal and out to sea, leading to salinity changes in and around the area. Salinity data has shown that the bay directly downstream of the central canal receives too much freshwater and at the wrong time, while the bay to the west of the central canal receives too little freshwater. The bay with more stable salinity is an important nursery area for sharks and other marine life. In order to improve the distribution of freshwater throughout the Ten Thousand Islands, land purchased by the State of Florida is being restored by the South Florida Water Management District. When complete, significant reductions in freshwater flowing from the canal will create more consistent flows and fewer effects on marine life from rapid salinity changes.

Drainage canals which are part of the Picayune Strand restoration project. Photo: US Army Corps of Engineers

Sharks indicate healthy salinity regimes

Sharks use shallow estuarine bays to give birth to their young. These back bays provide young sharks with food and protection from potential predators such as larger sharks. Sharks generally prefer saltier waters so areas with lower salinities may support fewer shark species. Research suggests that bull sharks (*Carcharhinus leucas*) may be more tolerant of low salinities than other sharks, freely moving from marine to more fresh locations. They are the dominant species caught in parts of Rookery Bay where salinity is lowest.

Bull sharks rely on estuaries such as Rookery Bay for food and protection. Photo: bigfishexpeditions.com

Shark data will test restoration success

Researchers are collecting shark demographic data to understand shark nursery areas and relative distributions before, during, and after restoration of the Ten Thousand Islands watershed. Three bays downstream of the canal are sampled each month from two hours before until two hours after sunset. Using a donated houseboat as home base, researchers monitor with a monofilament gill net and baited long lines. Captured sharks are carefully brought into the boat to be identified, tagged, measured, weighed, and released. Water conditions such as temperature and salinity are also recorded.

Researcher Pat O'Donnell releases a bull shark after it is measured, weighed, and tagged. Photo: RBNERR

Scientists are documenting the different types of sharks found in each location and how they react to changes in their environment. This ground-breaking research may also help scientists and managers understand how these top predators may be affected by climate change in the future, especially due to changes in the salinity of estuarine waters.

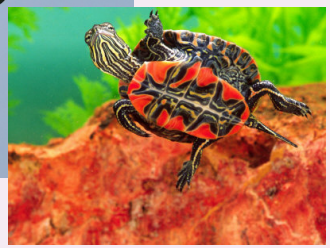
Contact: Patrick.Odonnell@dep.state.fl.us

"The Meadows" Land Acquisition in Alabama Will Mitigate Impacts of Climate Change

Weeks Bay National Estuarine Research Reserve

Land Purchase

The Weeks Bay National Estuarine Research Reserve (WBNERR) is located on the eastern shore of Mobile Bay, Alabama. It contains more than 6,000 acres of tidal and forested wetlands and receives freshwater from the Fish and Magnolia rivers. While it is a relatively small estuary, it supports numerous rare and endangered species including the brown pelican, eastern indigo snake, and the Alabama red-bellied turtle.



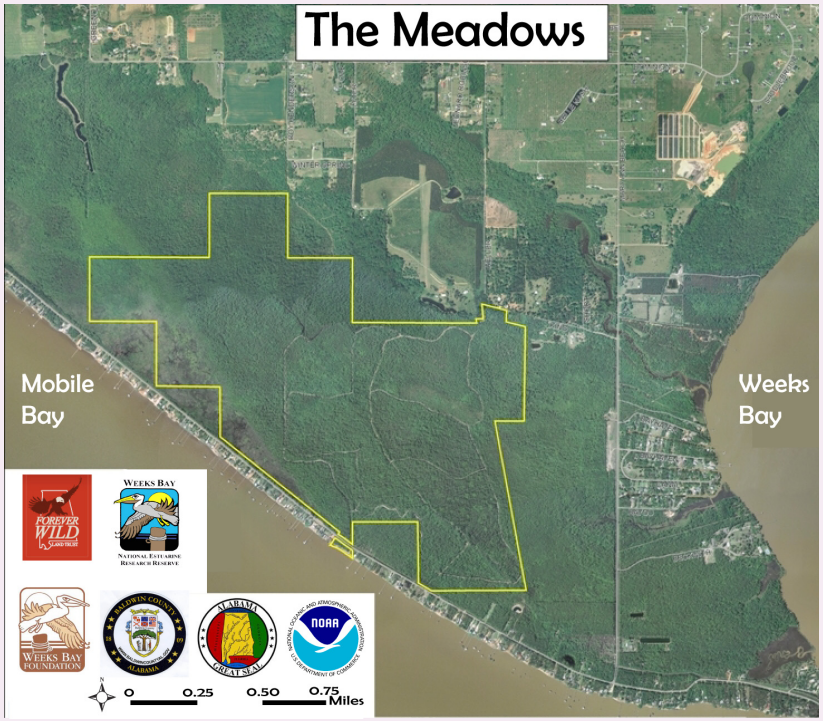
Brown pelicans and Alabama red-bellied turtles are among the rare and endangered species that rely on habitats in Weeks Bay Reserve. Photos: Terry Sohl, David Northcott.

Alabama Forever Wild program dedicated to protection through conservation

In recent years, the WBNERR has had the opportunity to partner with conservation agencies to acquire and protect important habitats. Forever Wild is Alabama's land trust program. It has made great strides in protecting the unique heritage of Alabama, acquiring more than 205,408 acres since 1992 using earnings from the Alabama Trust Fund, derived from gas royalties from Alabama's submerged lands in coastal waters.
The Forever Wild program has assisted acquisitions in the Weeks Bay area, adding conservation lands to the Reserve.

Strategic land acquisition targets areas that can buffer climate change impacts

Conservation partners are looking to the future and strategically targeting lands that have the potential to mitigate sea level rise and other climate change impacts.



Before purchasing a property, partners examine factors such as:

- Geomorphology (landforms such as dunes and processes that form them),
- Elevation, and
- Habitats types and their potential ability to migrate with sea level rise.

"The Meadows" property chosen to mitigate climate change impacts

A diverse partnership of federal, state, and county governments, and non-profit agencies formed to secure the acquisition of 820 contiguous acres of forested wetland habitats adjacent to the Reserve. The property contains elevation changes and upslope areas. As sea level rises, causing flooding and shoreline erosion in coastal areas, low-lying habitats will be able to migrate into protected upslope areas. The property is also expected to positively impact fisheries in the nearby Weeks Bay and Mobile Bay.

Contact: LG.Adams@dcnr.alabama.gov

Map of "The Meadows" conservation area, outlined in yellow, located along Mobile Bay; and logos of the partners involved. Source: WBNERR

Exploring Cost-Effectiveness of Restored Marshes as Nutrient Filters in World of Rising Seas

Weeks Bay National Estuarine Research Reserve and Grand Bay National Estuarine Research Reserve

Nutrient pollution is a worldwide ecological problem. When excess nutrients such as nitrogen and phosphorous enter waterbodies, they can cause algal blooms, poor water quality, and decreased oxygen availability for fish and wildlife. Nutrient pollution comes from many sources, including wastewater and industrial sources. One of the largest sources is urban and industrial runoff that enters waterbodies such as bays and estuaries as part of stormwater.

An example of a waterbody contaminated by excess nutrients, leading to an algal bloom. Photo: Lindsay Cross

Marshes provide "ecosystem services"

Marshes are proven filters of runoff pollution, but are being lost at alarming rates due to many factors, including development and sea level rise. Marshes provide other ecosystem services such as habitat for fish and wildlife, storm protection, and reduction of coastal erosion. With continued loss of marshes and the ecosystem services they provide, the health of coastal systems will diminish.

Restoration of marshes has been used as a way to mitigate for marsh loss and to restore ecosystem services such as nutrient reduction. However, scientific evaluation of many of these restoration efforts is lacking. Monitoring and scientific evaluation of restoration projects are critical to understand the magnitude of ecosystem services provided by restored marshes. When this information is combined with an analysis of project costs, it can lead to better and more cost-effective restoration projects.

Researchers address cost effectiveness of marsh restoration at two Research Reserves

Researchers from the Dauphin Island Sea Lab, University of South Alabama, University of Southern Mississippi, and the University of the Connecticut, with funding from Mississippi-Alabama Sea Grant, performed a marsh restoration cost-effectiveness project at the Grand Bay National Estuarine Research Reserve (GDBNERR). Based on results of that project, they are conducting a similar project at Weeks Bay National Estuarine Research Reserve (WBNERR) that will also address how marshes respond to rising sea levels.

Study used different planting densities

The marsh at Grand Bay was constructed by building a small riprap wall and backfilling sediment behind it. Researchers then planted black needlerush (*Juncus roemerianus)*, the dominant salt marsh plant along much of the Gulf coast, that was transplanted from a nearby natural marsh. Needlerush plots were planted with densities of 0%, 50% and 100% in order to test survival rate and ability to filter nutrients in runoff.

50% planting density most cost-effective

The 50% and 100% planting designs had similar vegetated coverage after two years. Both filtered upwards of 90% of incoming nutrient pollution, while the non-planted (0%) area filtered much less pollution at the end of the project. Project managers concluded that the 50% planting density is most cost-effective for both marsh expansion and nutrient filtration two years post-planting.

Grand Bay NERR restored marsh immediately after planting with 50% density on far right and 100% density in center. Photo: Chris May

Grand Bay NERR restored marsh two years after planting. Note that coverage for 50% and 100% areas are similar. Photo: Eric Sparks

Weeks Bay project builds on Grand Bay results and adds sea level rise component

Following up on these findings, a new project is under way at the Weeks Bay NERR that adds more planting designs and the aspect of sea level rise to the research plan. The magnitude of nutrient filtration and other ecosystem services provided by marshes may be altered with increases in sea level and will be evaluated to further inform restoration practitioners of how to perform more effective restoration in the future.

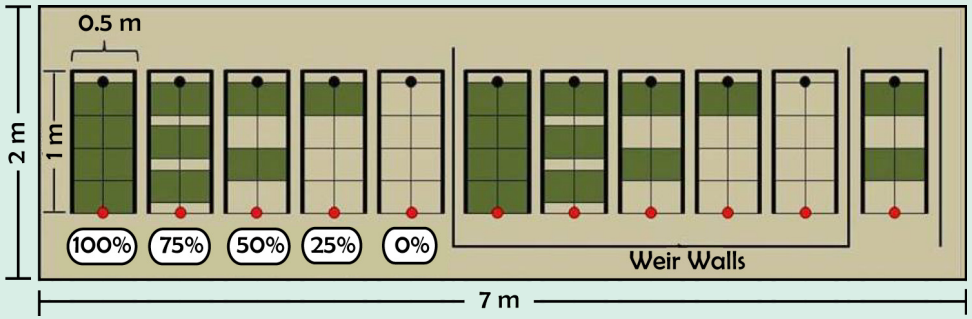
Restoration at the Weeks Bay location will occur at two nearby sites north of Weeks Bay. Source: Eric Sparks

This project is funded by the National Estuarine Research Reserve System Science Collaborative and the US Fish and Wildlife Service, with researchers from the Dauphin Island Sea Lab, University of South Alabama, University of Alabama, Northern Michigan University, and Mississippi Department of Marine Resources.

Design modified to control water levels

Restored marsh areas were constructed by placing COIR logs (coconut fibers tightly wound in a mesh tube) at the seaward edge of the target area and backfilling sediment where the black needlerush will be planted. Planting densities of 0%, 25%, 50%, 75%, and 100% were planted in February 2013 and will be evaluated for nutrient filtration capabilities, sediment accretion, and marsh health for two years. Half of the plants will be subjected to sea level rise conditions by surrounding them with a weir.

Site 2 of Weeks Bay NERR restored marsh during the construction. COIR logs were placed at the water's edge and backfilled with sediment. Photo: Eric Sparks



Experimental design for Weeks Bay NERR restored marsh. Green squares are planted plots of black needlerush. There are a total of 11 experimental plots [five outside of the weir (left), five inside the weir, and one weir control (right)]. Each restoration area contains three of the units pictured above. Black dots are where simulated nutrient pollution is introduced and red dots are where water samples are taken for analysis. Source: Eric Sparks

The weirs function by holding in high tides for longer periods of time and limiting the extent of low tide, thereby subjecting the plants to wetter conditions that simulate the soil saturation levels expected in 2050.

Weir within Weeks Bay NERR restored marsh. The PVC array controls the valve mechanisms that regulates water levels, simulating sea level rise. Photo: Eric Sparks

Results will improve effectiveness of future marsh restoration projects

The nutrient filtration capability and vegetated area of all restoration designs, both with and without sea level rise conditions, will be compared to the cost of constructing the marsh to estimate cost-effectiveness for individual planting designs. With this information, managers will be able to determine which design best suits their target restoration area and budget based on expected nutrient pollution loading and projected sea level rise in their systems.

Contact:
esparks4040@gmail.com

Step-by-Step Recommendations

Coastal ecosystems are vulnerable to many climate change impacts that will affect energy and water supplies, natural resources, and cultural and recreational assets. Without proper planning, policies, and response strategies, coastal communities may lose valuable services provided by the natural environment. While policies at the state and national level are an important component, it is essential that communities begin addressing their own vulnerabilities and developing long-term solutions. Having an awareness of climate change and how it may affect your community is the first step in creating workable solutions.

1. Begin by assessing your vulnerabilities

There are several exercises in which communities can participate to help them assess their current vulnerabilities.

Coastal Resilience Index (CRI) is a self-assessment program, administered through NOAA Coastal Services Center, that allows communities to predict if their community will reach and maintain an acceptable level of functioning after a disaster. It evaluates key indicators of resilience, including:

- Critical infrastructure and facilities,
- Transportation issues,
- Community plans and agreements,
- Mitigation measures,
- Business plans, and
- Social plans.

The CRI is supported by agencies such as the Gulf of Mexico Alliance and Gulf of Mexico Sea Grant which have staff that can assist communities in performing the exercise. Visit: http://www.southernclimate.org/documents/resources/Coastal_Resilience_Index_Sea_Grant.pdf

Community Rating System (CRS) is a voluntary program through the Federal Emergency Management Agency (FEMA) that evaluates floodplain management activities that exceed the minimum National Flood Insurance Program (NFIP) requirements. Communities can receive a discount of up to 45% on flood insurance rates by implementing projects that improve public safety, reduce damage to property and infrastructure and avoid economic disruption and loss such as preserving areas that repeatedly flood. Visit: http://www.fema.gov/national-flood-insurance-program-2/community-rating-system

A portion of the Mississippi River in lower Mississippi is flooded following a heavy rain event. Photo: standeyo.com

2. Map areas that may become inundated

Another useful step for communities is to examine which areas are likely to be inundated by storm surge, urban flooding, or sea level rise. There are many free mapping tools available online that can be tailored to a community's needs. Examples include:

- **Surging Seas** sea level rise analysis by Climate Central depicts SLR scenarios between 1-10 feet for major US coastal cities: http://sealevel.climatecentral.org/
- **Sea Level Affecting Marshes Model (SLAMM)** simulates the dominant processes involved in wetland conversion and shoreline modifications during long-term sea level rise. Visit: http://www.warrenpinnacle.com/prof/SLAMM/
- **NOAA Sea Level Rise and Coastal Flooding Impacts** examines impacts from 1-6 feet of sea level rise among portions of the US coast. It also addresses impacts to marshes, flood frequency and socioeconomic vulnerability. Visit: http://www.csc.noaa.gov/slr/viewer/#
- **NOAA Coastal Inundation Mapping** is a two-day course, using geographic information system (GIS) tools, for floodplain, coastal resources, and emergency managers. Visit: http://csc.noaa.gov/digitalcoast/training/inundationmap

3. Identify habitats that could be protected during disasters or for long-term preservation

Communities should identify valuable or sensitive ecosystems and how they could be protected during a disaster such as employing booms that prevent the entry of oil and other hazardous substances. Communities may also identify areas that, due to repetitive flooding from storm surge or sea level rise, could be returned to natural areas such as parks or preserves.

A boom near Pensacola, FL protects seagrass beds from oil following Deepwater Horizon spill. Photo: US Coast Guard

4. Prioritize strategies that provide habitat or wildlife benefits

Adaptation strategies that encourage habitat protection or creation, such as living shorelines, can result in storm protection for coastal areas, as well as enhanced habitat for fish and wildlife species. These may be used alone or in conjunction with other measures.

A living shoreline, constructed of rock or rip-rap material and planted with wetland plants, provides both shoreline protection and habitat benefits. Photo: Tracy Skrabal

5. Engage the business community

It is imperative that all community sectors are involved in climate change adaptation. Planning professionals, business leaders, and elected officials are important participants. Insurance agencies and those involved with emergency management should also be involved with discussions and planning.

It may be advantageous to look at the cost savings of proactively implementing strategies today rather than delaying action. In 2013 alone, the US government spent more than $100 billion on disaster relief. There may be incentives for businesses and industries that encourage adaptation planning that will result in greater resiliency and cost savings to taxpayers.

Photo: rosiemade.com

6. Develop post-disaster recovery plans

Many communities have or will initiate planning to prepare for and respond to natural resource disasters such as storms or hurricanes. These exercises are often multi-disciplinary, involving numerous governmental departments, ranging from human health, utilities, transportation, and environmental protection, as well as academic institutions, NGOs, and local businesses. This is an excellent opportunity to begin climate change-related discussions.

Adaptation planning can achieve other societal goals and improve communities

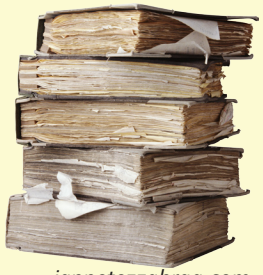
Climate change discussions and planning can ultimately lead to more resilient, engaged, and vibrant communities. Urban planning that prioritizes compact or mixed use developments, as well as green infrastructure techniques, results in less water and energy consumption, improved management of stormwater, and habitat benefits. Incorporating open space or recreational areas can provide an opportunity for interaction and foster a deeper sense of community.

Community planning may include mixed use developments that incorporate business, residential, transportation, and natural areas. Source: SRF Consulting

Resiliency starts with YOUR community!

While there is no "one size fits all" strategy for climate change resiliency, there are similarities in practices and opportunities to learn from others. The examples in this handbook highlight how communities can incorporate climate change resiliency as a component of on-going or future habitat protection and planning projects. Share this handbook in your community and embark on the road to resiliency today.

Recommended Readings


jannetezzahraa.com

The following recommended readings, while not an exhaustive list, will expand upon the ideas discussed in this handbook. Content from many of these references was included in this handbook. They are listed by title, primary author and/or funding agency, publication date, and electronic link, when available.

Adapting to Climate Change: A Planning Guide for State Coastal Managers. *National Oceanic and Atmospheric Administration. 2010. http://coastalmanagement.noaa.gov/climate/adaptation.html*

Climate Change 2013: The Physical Science Basis, Summary for Policy Makers. *Intergovernmental Panel on Climate Change (IPCC). 2013. www.climatechange2013.org*

Climate Scenarios: A Florida-Centric View. A White Paper on Climate Scenarios for Florida. *Vasubandhu Mistra. November 2011. http://floridaclimate.org/docs/climate_scenario.pdf*

Florida Homeowners Handbook to Prepare for Natural Hazards. *Gulf of Mexico Alliance and University of Florida IFAS Extension. May 2013. http://fl.stormsmart.org/handbook/ (Also available for other coastal states)*

Global Sea Level Rise Scenarios for the United States National Climate Assessment. *National Oceanic and Atmospheric Administration. December 2012. http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf*

Gulf of Mexico 360°: State of the Gulf of Mexico. *Harte Research Institute for Gulf of Mexico Studies. March 2013. www.gulf360.org*

Impacts and Adaptation Options in the Gulf Coast. *Center for Climate and Energy Solutions. June 2012. http://www.c2es.org/publications/gulf-coast-impacts-adaptation-options*

Incorporating Sea Level Change Scenarios at the Local Level. *NOAA Coastal Services Center. 2012. http://csc.noaa.gov/digitalcoast/publications/slcscenarios*

Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. *The Climate Impacts Group. September 2007. http://cses.washington.edu/cig/fpt/guidebook.shtml*

Restore-Adapt-Mitigate: Responding to Climate Change Through Coastal Habitat Restoration. *Restore America's Estuaries. April 2012. http://www.estuaries.org/images/stories/RAE_Restore-Adapt-Mitigate_Climate-Chg-Report.pdf*

Sea Level Changes in the Southeastern United States: Past, Present, and Future. *Gary T. Mitchum, University of South Florida. August 2011. http://www.seclimate.org/pdfpubs/201108mitchum_sealevel.pdf*

Synopsis of an Assessment: Policy Tools for Local Adaptation to Sea Level Rise. *Marine Policy Institute at Mote Marine Laboratory. October 2009. http://www.mote.org/clientuploads/MPI/Synopsis-Policy%20Tools%20for%20Local%20Adaptation%20to%20Sea%20Level%20Rise%28fin%29.pdf*

Synthesis of Adaptation Options for Coastal Areas. *EPA Climate Ready Estuaries. December 2008. http://water.epa.gov/type/oceb/cre/upload/CRE_Synthesis_1-09.pdf*

The State of the Climate in 2012: Special Supplement to the **Bulletin of the American Meteorological Society.** *J. Blunden and D.S. Arndt, Eds. August 2013. http://journals.ametsoc.org/doi/pdf/10.1175/2013BAMSStateoftheClimate.1*

Third National Climate Assessment Report (Draft). *US Global Change Research Program. 2012. http://ncadac.globalchange.gov/*

Tools for Coastal Climate Adaptation Planning: A Guide for Selecting Tools to Assist Ecosystem-Based Climate Planning. *Coastal-Marine Ecosystem Management Tools Network. 2013. https://connect.natureserve.org/sites/default/files/documents/EBM-ClimateToolsGuide-FINAL.pdf*

US Environmental Protection Agency
Office of Water
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460
www.epa.gov/cre

Tampa Bay Estuary Program
263 13th Ave S., Suite 350
St. Petersburg, FL 33701
www.tbep.org
info@tbep.org

Document available at: www.tbeptech.org/DATA/cre/gulfcoasthandbook.pdf