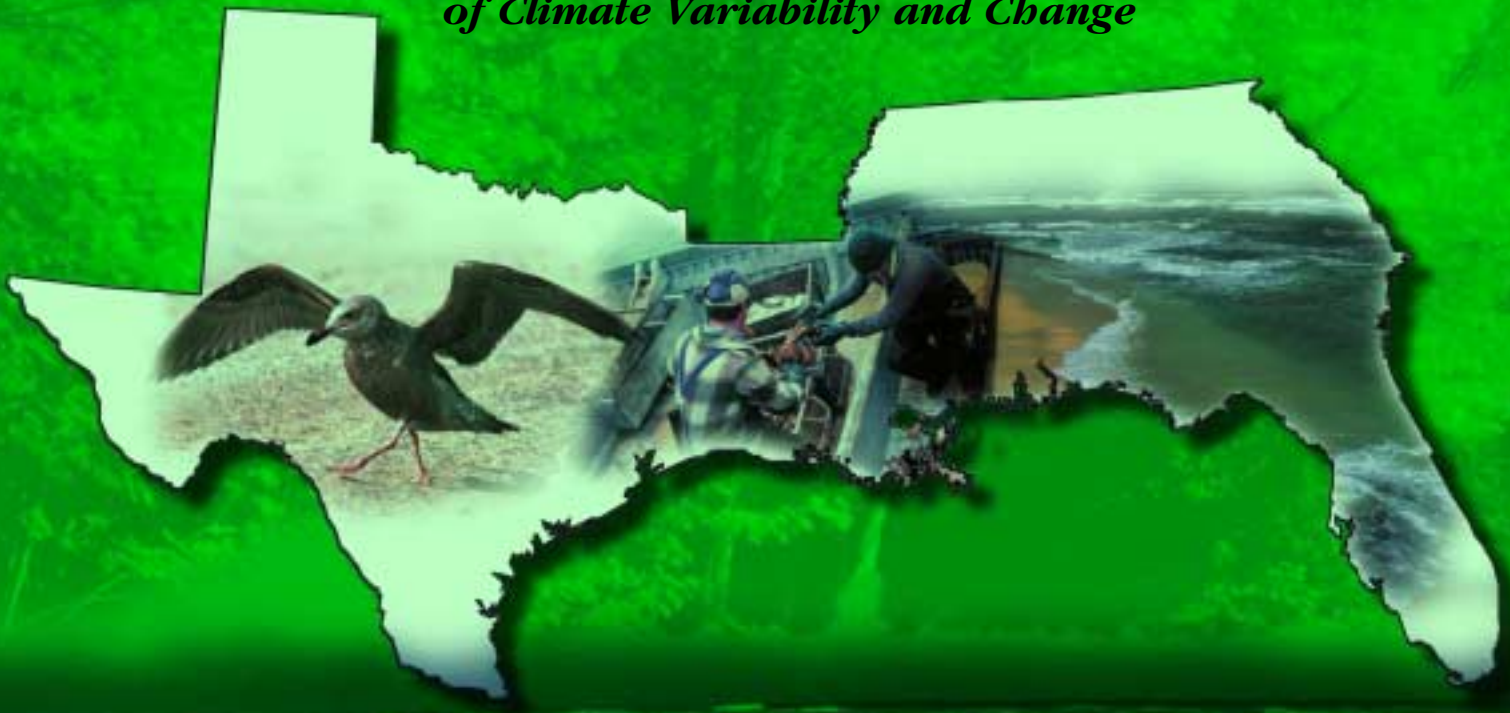


PREPARING FOR A CHANGING CLIMATE

*The Potential Consequences
of Climate Variability and Change*



Gulf Coast Region

*Findings of the
Gulf Coast Regional
Assessment*

Zhu H. Ning
R. Eugene Turner
Thomas Doyle
Kamran Abdollahi

June 2003

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INTRODUCTION



Context of Societal Concern with Climate Variability and Change

Over the past decades, scientific research has greatly advanced the knowledge and understanding of global environmental change. Research supported by the U. S. Global Change Research Programme (USGCRP) and research and assessment results by international organizations such as the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Program (WCRP), and the International Geosphere and Biosphere Programme (IGBP) have demonstrated that human activities exert powerful environmental influences on global, regional, and local scales. Recent findings by the Intergovernmental Panel on Climate Change (IPCC, 1997) indicate that human activities are increasing the atmospheric concentrations of carbon dioxide (CO₂) and other greenhouse gases such as nitrous oxide (NO_x), methane (CH₄), chlorofluorocarbons (CFCs), partially halogenated fluorocarbons, and ozone (O₃), which alter radiative balances, and tend to warm the Earth's surface.

These changes in greenhouse gases and aerosols constitute key factors in global and regional changes in temperature, precipitation, and other climate variables, resulting in local and regional changes in soil moisture, an increase in global mean sea level, and prospects for more severe extreme high temperature events, floods, and droughts in some places. In the United States and elsewhere in the industrialized world, energy use contributes to global warming more than any other human activity. This is because most of our energy comes from carbon-based fossil fuels (coal, oil, and natural gas). Fossil fuels provide energy for a variety of purposes, including transporting goods and people, manufacturing products, heating and cooling buildings, lighting spaces, and cooking foods. Each year U.S. energy use releases more than 5.5 billion tons of carbon dioxide into the atmosphere.

Present global CO₂ concentrations in the atmosphere are 130% of pre-industrial levels (Figure 1). The global surface temperature last century is warmer than any other century in the past millennium. The global average temperature has increased by about 1°F over the last century and is projected to rise another 2-6.5°F by year 2100 (Figure 2). The last two

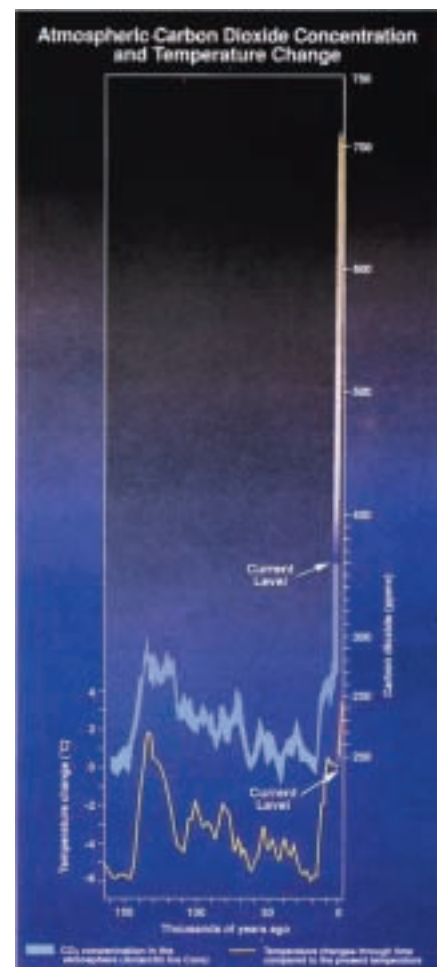


Figure 1. The CO₂ level has increased sharply since the beginning of the Industrial Era and is already outside the bounds of natural variability seen in the climate record of the last 160,000 years. Continuation of current levels of emissions will raise concentrations to over about 700ppm by 2100, a level not experienced since about 50 million years ago. From Ning, 1999, adapted from Climate Change State of Knowledge.

decades have been the warmest last century. Average global sea level has risen about 4 to 10 inches in the last hundred years, and is projected to rise another 6-38 inches by year 2100. Mid- and low- latitude mountain glaciers have retreated world-wide last century.

As greenhouse gases continue to accumulate in the atmosphere, it is expected that an increase in rainfall amount and consequent increase in river flooding will occur. Recent floods in the Gulf Coast areas (1993, 1997) are examples of such events, and perhaps indicate the high sensitivity of flood occurrence to changing climate. Because of its unique location adjacent to the Gulf of Mexico, the Gulf Coast region of the United States is particularly vulnerable to various environmental alterations resulting from climate change.

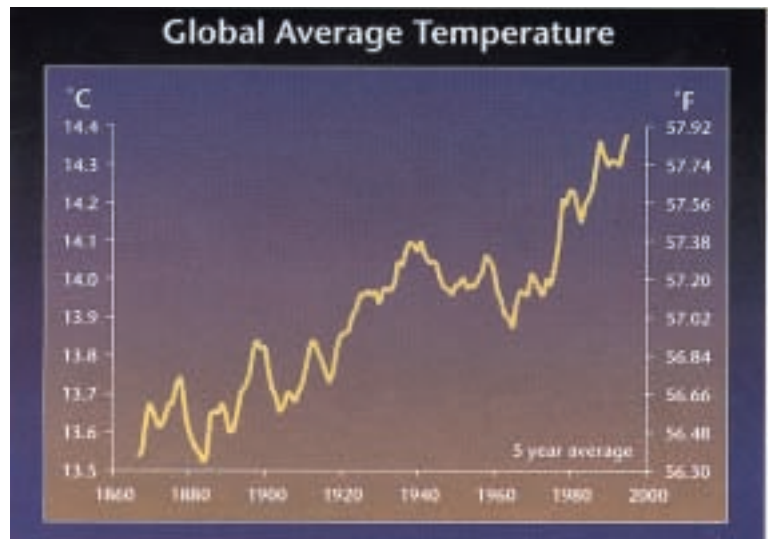


Figure 2. The global average temperature has risen by approximately 10°F over the last century. From Ning, 1999, adapted from Climate Change State of Knowledge.

The Region and the Regional Assessment Process

The Gulf Coast region includes the five Gulf Coast states. The Gulf Coast assessment includes the Gulf Coastal Plains and coastal waters of southern Texas, southern Louisiana, southern Mississippi, southern Alabama, and western Florida (Figure 3). The Gulf itself has a surface area of 1.63 million square kilometers (630,000 square miles) and a watershed area of 4.69 million square kilometers (1.81 million square miles) in the United States. This region is one of the nation's largest ecological systems and is closely linked to a significant portion of the nation's economy. Petroleum production, fisheries, agriculture, forests, and tourism rank among the most significant sectors of the Gulf Coast region's economy. The Gulf has five of the nation's top ten fishing ports. Gulf ports handle one half of the nation's import-export tonnage and the Gulf produces 72% of the nation's offshore petroleum production. The Gulf Coast region relies on many natural resources to fuel many important sectors of its economy.

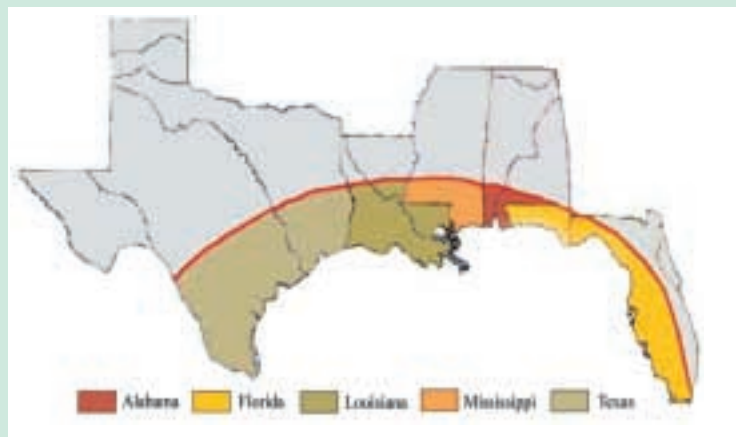


Figure 3. The Gulf Coast region define for the first National Assessment.

Assessment First Phase - the Regional Assessment Workshop

The regional assessment team, sponsored by the USEPA, began by hosting a Gulf Coast Regional Climate Change Workshop and Public Forum on February 25-27, 1998. The workshop participants identified many characteristics and their potential consequences as a result of projected climate variability and change that are distinctive to the region. Also, the workshop participants identified numerous specific issues of regional concern including coastal ecosystems, forests, water and air quality, fisheries, commerce, industry, and energy, as the key sectors that they believe are vulnerable to climate change. Chapter 2 of this publication summarizes the key findings of these key sectors/issues at the workshop.

Significant technical contributions to the Workshop were provided by the Workshop Steering Committee members. The steering committee members represented Southern University, the US Global Change Research Programs (USGCRP), the White House Office of Science and Technology Policy (OSTP), the National Wetland Research Center (NWRC), Science and Engineering Alliance (SEA), Southern Regional Climate Center (SRCC), National Center for Atmospheric Research (NCAR), NASA, USDA Forest Service, Louisiana State University (LSU), Florida State University (FSU), and Tulane University.

The workshop focused on identifying the regional vulnerabilities to climate variability and change and on obtaining information that when aggregated across regions would support the National Climate Change Assessment. It also contributed to the international assessment activities and the work of IPCC. The specific objectives of the workshop were to:

- (1) Identify current stresses and issues of concern in the region;
- (2) Examine how an increase in climate variability and climate change might interact with the current stresses;
- (3) Discuss information needs that will further the assessment process;
- (4) Identify possible coping mechanisms and define a regional research agenda; and
- (5) Design regional follow-up assessment activities.



Figure 4. A breakout session at the Gulf Coast Regional Climate Change Workshop.

More than 200 scientists, policy makers, stakeholders, industry representatives, state, regional, and national experts attended the workshop (Figure 4). African Americans, Asians, Hispanics, and Native Americans in the region were well represented. In addition, the Workshop included participants from the Canadian Ministry of the Environment, and international scientists and students.

The workshop was extensively covered by the media including eight newspaper articles, four TV news reports, and four radio news reports. Based on the Workshop results, a report was compiled by the project directors and the breakout session leaders. The report (USGCRP, 1998a) reflects the Workshop's scope, participation, program, recommendations,

and findings. It also includes transcripts of the presentations made by some of the plenary speakers and keynote speakers. The Workshop Steering Committee provided an opportunity for the participants to enhance their contribution through a peer-reviewed compendium, which was published in addition to the Workshop final report (Ning, 2000). It includes articles on climate change and related research findings, climate projections (modeling efforts), and overviews on important regional issues.

The Workshop is part of the effort to elucidate the present and potential consequences of climate variability and change, both detrimental and beneficial. This Workshop also explored these consequences in relation to the pressures created by other long-term stresses on the environment and society. We used the Workshop's findings and recommendations from the Workshop to adjust the directions of the assessment research program. This Workshop helped the regional participants to increase their understanding of what is known, unknown, and uncertain in relation to the potential consequences of climate variability and change for the Gulf Coast region. The Workshop also provided helpful information to those who protect and utilize our nation's natural resources, provide for our food, fiber, and economic resources, and determine local, national, and international policies.

Assessment Second Phase - The Regional Assessment Activities

The integrated assessment of potential consequences of climate change for the Gulf Coast region began following the Workshop. Of the many sectors/issues identified through the Workshop effort; due to time and resource constraints, two sectors, coastal ecosystems and maritime forest resources, were chosen for a series of case studies (Table 1).

Table 1

Key sectors/issues and relevant case studies presented in Chapter 3 (Coastal ecosystems) and 4 (maritime forest resources).

KEY ISSUES	CASE STUDIES
Coastal Ecosystems	
Sea - Level Rise	Impact of sea - level rise on coastal landscapes
Hypoxia	Climate change impacts on low oxygen zones and its effects on fisheries
Salt Water Intrusion	Assessing the potential climate change impacts on salinity in northern Gulf of Mexico estuaries
Flooding	Assessing and modeling flood events and climate change
Maritime Forests	
Forest Health and Species Distribution	Climate change impacts on the health and distribution of mangrove communities
Vegetation Habitat	Predicting the effects of sea-level rise on coastal vegetation habitat
Hurricane and Forest Fire	Vulnerability of the Gulf Coast to intense hurricane strikes and forest fires in the light of long-term climatic change

The major findings of the assessment case studies are summarized in chapter 3 and 4. The overall goal of the integrated assessment effort was to analyze and evaluate potential consequences of climate variability and change for the region in the context of other pressures on the people, environment, and natural resources. Specific study objectives were to:

1. Select and apply climate scenarios/models, ecosystem models, and socio-economic trend scenarios to regional data bases;
2. Assess climate change impacts on sectors within the region with an emphasis on coastal ecosystems and maritime forests;
3. Identify coping strategies and research needs; and
4. Undertake outreach efforts to stakeholders especially minority communities, small limited resource farmers, minority farmers, small forest woodland owners, and socially and economically disadvantaged communities.

The regional assessment recognized the interrelationship between the physical or natural environment and humankind. This relationship balances the environmental and economic attributes of a region by linking the goals of environmental protection and economic development. Ecological, economic, social, and cultural aspects of the coastal ecosystems and maritime forests were incorporated into the assessment process. They were horizontally integrated and vertically integrated beginning with climate scenarios, including ecosystem models, and finally socioeconomic trends. Assessment of key issues was performed by well-qualified scientists through case studies, which added substance to the assessment. Case study results also provided sound and scientific data to support the impact projections and analyses. Each case study answered questions related to key issues.

The lead institution, Southern University and A&M College (SU), is a 1890 land-grant Historically Black College and University (HBCU). Southern University is the largest and the only historically black university system with 5 campuses and is optimally positioned to serve African American and other minority communities in the Gulf Coast region. To promote regional participation, this assessment was accomplished by the joint efforts of Southern University, Louisiana State University, National Wetland Research Center, and Alabama A&M State University (an HBCU).

Outreach and stakeholder involvement were also a fundamental component of the assessment. The stakeholder network that was initially established by SU through the Gulf Coast Regional Climate Change Assessment Workshop was expanded. Stakeholders included policy makers, managers, planners, scientists, private business owners, farmers, fishermen, minorities, and low-income communities. Outreach meetings were hosted to obtain detailed information on key issues, concerns, coping strategies, and information needs.

The assessment provided answers to four questions: 1. What are the current environmental stresses and how are they likely to play out in the future without a change in climate or climate variability? 2. How will a change in climate or climate variability affect these environmental stresses? 3. How can people cope with climate variability and change in ways that mitigate other environmental stresses? 4. What research is needed to better estimate the consequences of climate variability and change?

The National Assessment Process

To help prepare the nation for climate variability and change, the USGCRP, in cooperation with the Whitehouse Office of Science and Technology Policy (OSTP), has engaged in a comprehensive effort to implement a national assessment process (USGCRP 1998b). These efforts began in early 1997 with a series of regional workshops, and have included a National Forum. The National Assessment Working Group (NAWG) composed of representatives of the federal sponsoring agencies was established to link agencies with the regions and sectors in the assessment. The National Assessment Synthesis Team (NAST) was also established with primary responsibility for the sectoral assessment and overall synthesis. The NAST drew up a strategy for using climate and socioeconomic scenarios in the regional and sectoral portions of the National Assessment. These efforts contributed to the development of a comprehensive plan for the National Assessment to involve 20 regions, 5 sectors, and a synthesis, all led by teams of scientists, managers, and other stakeholders who are committed to understanding the nation's vulnerabilities and to identifying the most rewarding ways of responding to future change. Regional analyses identified and characterized potential consequences in each of specific geographic regions. Sectoral analyses considered the potential consequences on major economic sectors such as agriculture and forestry, environmental sectors such as water resources and coasts, and societal sectors such as human health. These analyses were quantitative and national in scope. The national synthesis has drawn together the results of the regional and sectoral analyses, and from the scientific literatures.

The assessment process (1) was founded on the principles of scientific excellence and openness; (2) was designed to be comprehensive, integrative, and iterative; (3) linked research by scientists to specific needs of the stakeholders; and (4) provided planners, managers, organizations, and the public with the information needed to increase resilience to climate variability and cope with climate change. The National Assessment has been conceived as an ongoing process to continue beyond the publication of the first reports, eventually also dealing with other global change-related issues.

• REFERENCES •

- IPCC 1997. The Regional Impacts of Climate Change: An Assessment of Vulnerability Summary for Policy Makers. Watson Rt, Sinyowera MC and Moss RH eds. Intergovernmental Panel on Climate Change. United Nations Environment Programme.*
- Ning, Z.H. and K.K. Abelollabi 2000. Current Stresses and Potential Vulnerabilities: Implications of Global Change for the Gulf Coast Region of the United States. GCRCC and Franklin Press.*
- USGCRP 1998a. Gulf Coast Regional Climate Change Workshop Report, compiled by Zhu H. Ning and the regional assessment team members for the USGCRP, can be found at <http://www.nacc.usgcrp.gov/regions/gulfcoast.html>*
- USGCRP 1998b. The National Assessment Background Information, at USGCRP Website: <http://www.nacc.usgcrp.gov/background.html>*

CHAPTER 1. THE REGIONAL PERSPECTIVES



1.1 The Gulf Coast Region's Natural and Human Environment

1.1.1 The Physiogeographic Regions

The specific territory covered by the regional assessment encompasses the Gulf Coastal plains and coastal waters of southern Texas, southern Louisiana, southern Mississippi, southern Alabama, and western Florida (Figure 1). Wetlands are a typical landscape in the Gulf Coast area. Wetlands include areas where the water table is usually at or near the surface or where the land is covered by shallow water. These habitat types are abundant along the coast of the Gulf of Mexico. Wetlands may be forested, such as swamps and mangroves, or nonforested, such as



Figure 1. The Gulf Coast region defined by the National Climate Change Assessment.

marshes, mudflats, and natural ponds. Large areas of nonforested wetlands are found in coastal Texas, Louisiana, and Florida. Recent state estimates of coastal wetlands acreage (both forested and unforested) are: Alabama (121,603 acres); Florida (2,254, acres); Louisiana (3,910,664 acres); Mississippi (64,805 acres); and Texas (412,516 acres) (Ringold and Clark, 1980).

Alabama

Most of southern Alabama is less than 500 feet (150 meters) above sea level. The surface of the state rises gradually toward the northeast. Alabama has six main land regions: (1) the East Gulf Coastal plain, (2) the black belt, (3) the piedmont, (4) the Appalachian Ridge and Valley Region, (5) the Cumberland Plateau, and (6) the Interior Low Plateau (Figure 2). The East Gulf Coastal plain is Alabama's largest land region. It covers the entire southern two-thirds of the state, except for a narrow strip of land called the black belt. In western Alabama, the plain extends north almost to Tennessee. The plain has several sections. The low, swampy land of the Mobile River Delta makes up the southwestern section. The southeastern part is called the Wiregrass area. It is named for a tough grass that once grew there in pine forests. Today, the Wiregrass area is an important farming region. The northern part of the plain is often called the Central Pine Belt because many pine forests cover

The physiogeographic descriptions of the five Gulf Coastal states in this section are based on information obtained from *Geomorphology and Land Management in Changing Environment* by Duncan, et al, 1995, *The World Book Encyclopedia*, 1998, and the *New Encyclopedia Britannica*, 1998.

its low, rolling hills. In the western part of this section, the soils are gravelly and sandy, and are not good for growing crops.

The black belt is a narrow strip of rolling prairie wedged between the northern and southern parts of the East Gulf Coastal plain. The black belt was named for the sticky black clay soils of its rolling uplands. Early in Alabama history, farmers developed large cotton plantations in this region. Boll weevils, agricultural pests, came to the black belt in 1915, and damaged the cotton crop. Some farmers then changed from growing cotton to raising livestock.

The piedmont in east-central Alabama, is an area of low hills and ridges separated by sandy valleys. The clay soils of these hills and ridges have been badly eroded. Most of the land is forested. Cheaha Mountain, the highest point in Alabama, rises 2,407 feet (734 meters) on the northwestern edge of the Piedmont.

The Appalachian Ridge and Valley Region is an area of sandstone ridges and fertile limestone valleys. It lies northwest of the piedmont. The region has coal, iron, oil, and limestone—the three basic minerals used in making iron and steel.

The Cumberland plateau, also known as the Appalachian plateau, lies northwest of the Appalachian Ridge and valley region. The surface varies from flat to gently rolling land. It reaches a height of about 1,800 feet (549 meters) above sea level in the northeast. The land slopes to about 500 feet (150 meters) where it meets the East Gulf Coastal plain in the southwest.

The interior low plateau lies in the northwestern part of the state. Much of the land is in the valley of the Tennessee River.

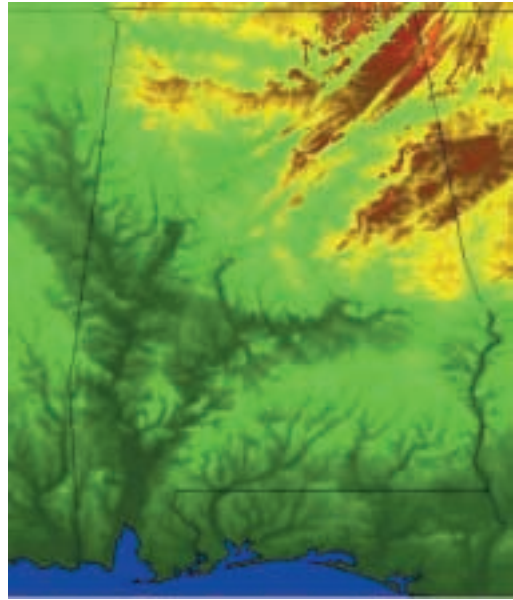


Figure 2. The Alabama territory covered by the Gulf Coast regional assessment.

Florida

Florida is part of the Atlantic Gulf Coast plain, a large land region that extends along the coast from New Jersey to southern Texas. Within Florida, there are three main land regions: (1) the Atlantic Coastal plain, (2) the East Gulf Coastal plain, and (3) the Florida uplands (Figure 3). The Gulf Coast regional assessment included only southwestern Florida, which is in the East Gulf Coastal plain land region.

The East Gulf Coastal plain of Florida has two main sections. One section covers the southwestern part of the peninsula, including part of the Everglades and Big Cypress Swamp. The other section of Florida's East Gulf Coastal plain curves around the north edge of the Gulf of Mexico across the panhandle to Florida's western border. The East Gulf Coastal plain is similar to the Atlantic coastal plain. Long, narrow barrier islands extend along the Gulf of Mexico coastline. Coastal swamps stretch inland in places.

The Big Cypress Swamp and the Everglades cover most of southern Florida. The Everglades include 2,746 square miles (7112 square kilometers) of swampy grassland. Water covers much of this region, especially during the rainy months.

The Florida Keys makes up the southernmost part of the state. These small islands curve southwestward for about 150 miles (241 kilometers) off the mainland from Miami. Key Largo is the largest island.



Figure 3. Florida territory covered by the Gulf Coast regional assessment.

Louisiana

Most of Louisiana was once part of an ancient bay of the Gulf of Mexico. The Mississippi and other rivers flowing from the north brought huge amounts of silt to the bay. This action over thousands of years built up the land area to its present size. Louisiana has three main land regions. All are part of the fertile low land that lies along the Gulf Coast of the United States (Fig. 4). These regions are (1) the East Gulf Coastal plain, (2) the Mississippi alluvial plain, and (3) the West Gulf Coastal plain.

The East Gulf Coastal plain in Louisiana covers the area east of the Mississippi river and north of Lake Pontchartrain. It rises gradually from marshes in the west and south to low, rolling hills in the north.

The Mississippi alluvial plain lies along the lower Mississippi river. In Louisiana, it reaches from the Arkansas state line to the Gulf of Mexico. Broad, low ridges and hollows parallel the river as it winds down the plain. The high fields atop the ridges are called frontlands. The frontlands slope away from the river to the backlands, which are great stretches of clay and silt. The backlands have several ancient channels of the Mississippi, far from its present course. The Mississippi Delta was formed by silt brought to the river's mouth. It covers about 13,000 square miles (33,700 square kilometers)-about a fourth of Louisiana's total area. The delta has the state's most fertile soil.

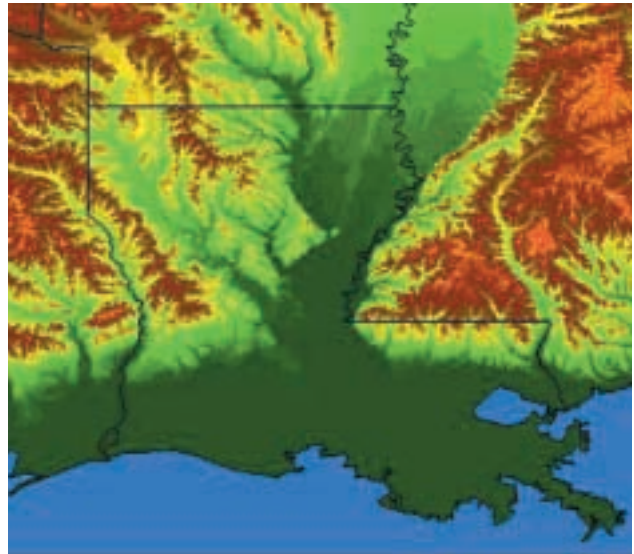


Figure 4. Louisiana territory covered by the Gulf Coast regional assessment.

The West Gulf Coastal plain includes all of Louisiana west of the Mississippi alluvial plain. At the southern end of the plain, low sand ridges called barrier beaches lie along the Gulf of Mexico. Behind these beaches, marshes stretch inland for about 20 miles (32 kilometers). Beneath the marshes and the coastal and offshore waters are large underground formations called salt domes. These domes cap great deposits of salt. Pools of natural gas and

petroleum are trapped along the sides of the salt deposits. Sulfur is sometimes found in the top of the domes between the salt and the upper crust.

North of the marshlands, the gently rolling Louisiana prairies-about 60 miles (100 kilometers) wide-reach westward across the plain to Texas. North of the prairies, the land rises gradually as it stretches toward Arkansas. The highest point in Louisiana is 535-foot (163-meters) Driskill Mountain, about 40 miles (64 kilometers) from the Arkansas line.

Mississippi

Mississippi has two main land regions: (1) the Mississippi alluvial plain, and (2) the east Gulf Coastal plain (Figure 5).

The Mississippi alluvial plain covers the entire western edge of the state. It consists of fertile lowlands and forms part of the 35,000-square-mile (90,600-square-kilometer) alluvial plain of the Mississippi River. The region is quite narrow south of Vicksburg. North of the city, the plain spreads out and covers the area between the Mississippi and the Yazoo, Tallahatchie, and Cold Water rivers. Floodwaters of the rivers have enriched the soil of the region with the deposits of silt. The fertile soil of the Mississippi alluvial plain is famous for its cotton and soybean crops. Most Mississippians call this region the Delta.

The East Gulf Coastal plain extends over all the state east of the alluvial plain. Most of the region is made up of low, rolling, forested hills. The coastal plain also has prairies and lowlands. Yellowish-brown loess (soil blown by winds) covers the region in the west. Most

Mississippians call these deposits the cane, bluff, or loess hills. The Tennessee River hills rise in northeastern Mississippi. They include the highest point in the state, 806-foot (246-meter) Woodall Mountain. The Pine Hills, often called the Piney Woods, rise in the southeastern part of the region. They are covered largely with longleaf and slash-pine forests.

The main prairie is called the black belt or black prairie because its soil is largely black in color. This long, narrow prairie lies in the northeast section of the state. The black belt stretches through 10 counties. Livestock graze there, and corn and hay grow well on the farmlands of the black belt. Small prairies also lie in the central Mississippi, east of Jackson. Along the Mississippi Sound, lowlands stretch inland over the southern portion of the region.

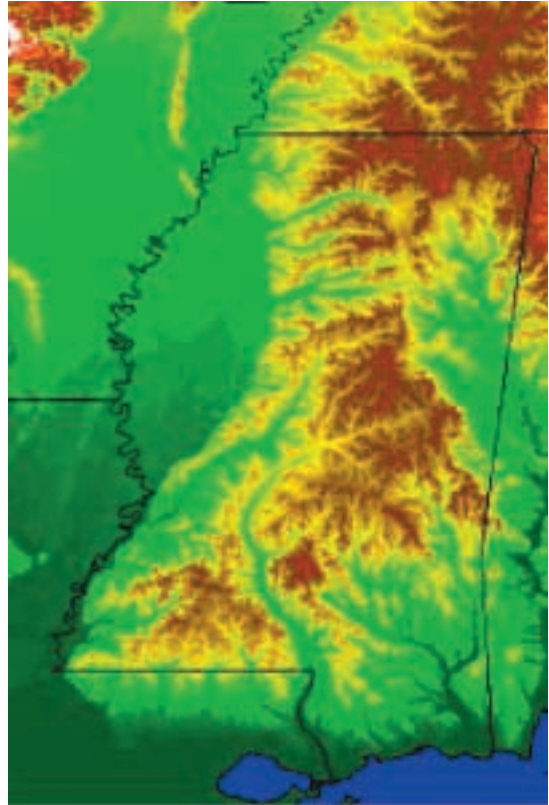


Figure 5. Mississippi territory covered by the Gulf Coast regional assessment.

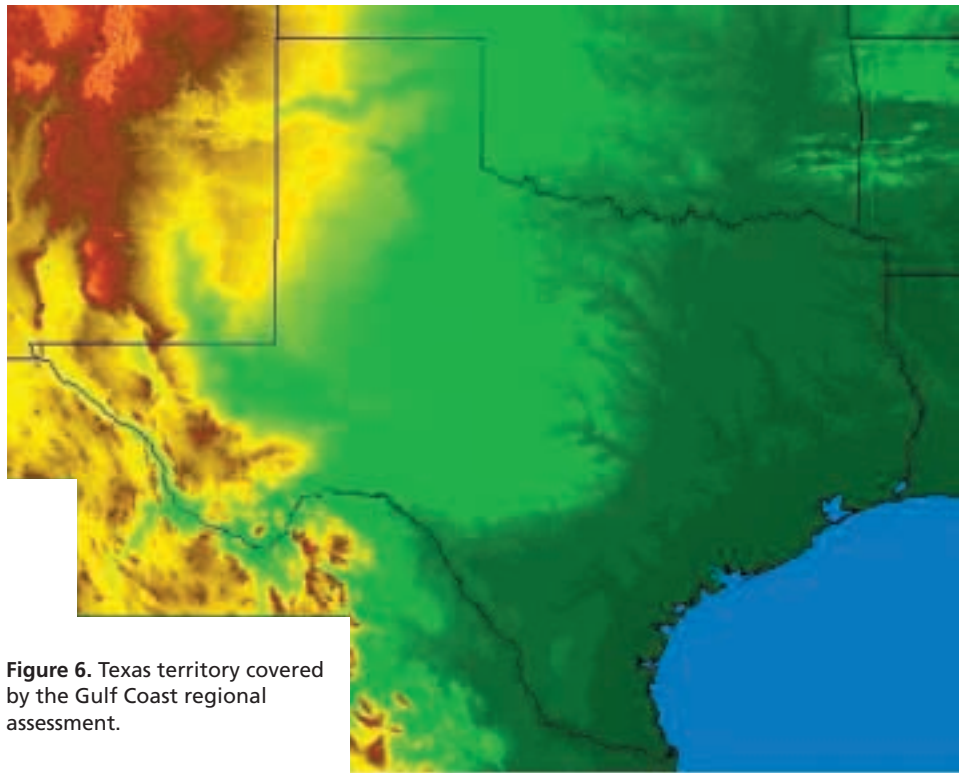


Figure 6. Texas territory covered by the Gulf Coast regional assessment.

Texas

Texas has five primary land regions. These are, from east to west: (1) the Gulf Coastal plains, (2) the prairie plains, (3) the rolling plains, (4) the Great Plains, and (5) the basin and range region (Figure 6). The parts of the state that are included in the regional assessment were the southern areas and coastal areas, mainly the Gulf Coastal plains, the prairie plains, and the coastal waters.

The Gulf Coastal plains of Texas are part of the fertile lowland that lies along the entire gulf coast of the United States. They range in elevation from sea level to about 300 feet (91 meters) above sea level. A subtropical region extends along a large part of the coast.

The southernmost part of the coastal plains consists of the fertile Rio Grande Valley. Just north of this valley lies the Middle Nueces Valley, part of the Nueces Plains. The two valleys are famous for their winter vegetables and fruits. The region along the coast from the Rio Grande Valley to Louisiana has rich soils. Cotton and several types of grain thrive in this region.

The northeastern part of the plain is a timberland with thick forests of oak, pine, sweet gum, and other trees. This area is often called the Piney Woods. Major lumber and paper companies own most of the land. Farmers in this area raise beef and dairy cattle and poultry. The region has many large mineral deposits.

The prairie plains lie west of the forest belt of the coastal plains. The prairie plains feature alternating belts of rugged hills and rolling hills. The rugged hills are covered with oak and hickory forests. The region includes the fertile Black Waxy Prairie. The prairie has rich soils for farming.

1.1.2 Coastline

Alabama

Alabama's general coastline extends for 53 miles (85 kilometers) along the Gulf of Mexico. The tidal shoreline, which includes small bays and inlets, is 607 miles (977 kilometers) long.

Mississippi

Mississippi has a coastline of 44 miles (71 kilometers) along the Gulf of Mexico. With bays and coves, it has a total shoreline of 359 miles (578 kilometers). The largest bays include Biloxi, St. Louis, and Pascagoula. The nation's longest sea wall protects about 25 miles (40 kilometers) of coastline between Biloxi and Point Henderson at Pass Christian. Other coastal towns include Bay St. Louis, Gulfport, and Ocean Springs. Deer Island is near the mouth of Biloxi Bay, and a chain of small islands lies off the coast. They include Cat, Horn Ship, and Petit Bois islands. Mississippi Sound separates them from the mainland.

Louisiana

Louisiana has a general coastline of 397 miles (639 kilometers) along the Gulf. But the marshy coast has been made extremely uneven by silt deposits. As a result, Louisiana's tidal shoreline – including bays, offshore islands, and river mouths – is 7,721 miles (12,426 kilometers) long. Salt water from the Gulf of Mexico enters the coastal waters through canals. It kills many of the freshwater marsh plants that help hold coastal soils in place, and as a result, large amounts of these soils are washed away. About 50 square miles (130 square kilometers) of Louisiana's coastal land erodes annually.

Florida

The coastline of Florida is 1,350 miles (2,173 kilometers) long divided into Atlantic Coast and the Gulf Coast. The Atlantic coast has 580 miles (933 kilometers) of shoreline. The Gulf coast is 770 miles (1,240 kilometers) long.

Texas

The general coastline of Texas is 367 miles (591 kilometers) long along the Gulf. The tidal shoreline, including bays, offshore islands, and river mouths, is 3,359 miles (5,406 kilometers) long. A series of narrow sand bars, enclosing shallow lagoons, lie along the Texas coast. These sand bars help protect the coast from ocean storms and huge, destructive waves called tsunamis. The Texas coast has 27 artificially created ports, that were once filled by silt left by the many streams emptying into the Gulf of Mexico. When they were filled by silt, only small vessels could use them. By removing the silt and deepening the harbors, engineers built 12 deepwater ports and 15 ports for barges and small ships.

1.2 Regional Climate Perspective

1.2.1 General Regional Climate: Present

Alabama

Alabama has a mild climate. January temperature averages about 52°F in the southern part of the state, and about 46°F in the north. July temperatures average about 80°F throughout

the state. Alabama's annual precipitation averages from about 65 inches on the coast to 53 inches in the north. Snow falls in the north, but is rare on the coast.

Florida

Most of Florida has a warm, humid climate similar to that of the other southern states. Florida's southern tip has a tropical wet and dry climate like that of Central America and large parts of Africa and South America. Nearly all of Florida's precipitation occurs as rain. Florida has an average yearly precipitation of 54 inches. An average of 32 inches falls in the rainy season, which lasts from May to October.

Louisiana

Most of Louisiana has a hot, humid, subtropical climate. It is one of the wettest states, with a yearly average of 57 inches of precipitation. Southern Louisiana has an average January temperature of 55°F, and a July average of 82°F. Hurricanes sometimes strike the coastal areas of Louisiana, causing loss of life and damage to property.

Mississippi

Mississippi has a warm, moist climate with long summers and short winters. In July, Mississippi temperatures average about 81°F. Winds from the Gulf of Mexico and frequent thundershowers cool much of the state during the summer. January temperatures average 46°F in Mississippi. Mississippi's precipitation ranges from about 50 inches a year in the northwestern part of the state to about 65 inches in the southeast. Hurricanes sometimes sweep northward from the Gulf in late summer and fall.

Texas

The climate of Texas ranges from subtropical in the lower Rio Grande Valley to moderately temperate in the northwest. Along the Gulf of Mexico, the coast has a warm, damp climate. There, winds from the Gulf reduce the heat of summer and the cold of winter. Rainfall in Texas decreases from east to west. East Texas averages 46 inches of precipitation a year. Part of west Texas averages only 12 inches a year.

1.2.2 Observed Regional Climate Trends

The Gulf Coast regional temperature during the 20th century has increased from the turn of the century until the 1950s, when a significant cooling took place (Easterling et al., 1996). Beginning in the late 1950s, a general warming trend has been re-established. The largest warming during the last century in the Southeast of the US has occurred along the Gulf Coast region. Much of the warming since the 1950s is the result of warmer winter temperatures (Figure 7).



Figure 7. Observed 20th century temperature trend in the Southeast and the Gulf Coast region of the US. The largest warming during the last century has occurred along the coastal region. From NAST, 2002.

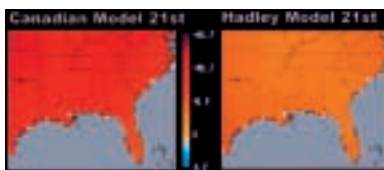


Figure 8. Observed precipitation changes during the last century are a patchwork of moderate increases and decreases. From NAST, 2002.

Dating back to 1895, the annual precipitation in the region shows 20-30% increase and the most recent ten years are appear even wetter (Figure 8).

The data clearly showed an increase in precipitation during the 1990s (Figure 9). Data for 1997 from the National Climate Data Center (Crowe and Quayle in Ning, 2000) indicated record precipitation in many parts of the Gulf Coast region, which was enhanced by the strong El Niño event (Figure 10).

The strong El Niño event, that created anomalous weather in many parts of the globe, contributed to 1997 being the warmest year of the century. El Niño also contributed to the excess moisture along the Gulf Coast region during that time period. The record shows that the Gulf Coast region precipitation for 1997 departed from 1961-90 normals, which is consistent with a strong El Niño contribution.

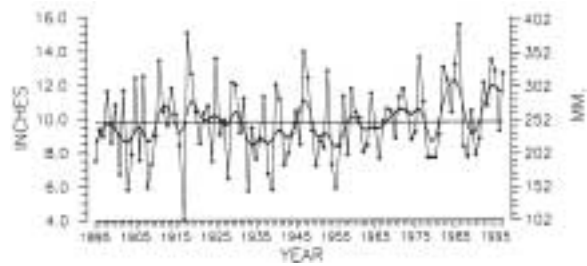


Figure 9. A time series of Oct-Dec average precipitation of the Gulf Coast region dating back to 1895. Note wet period during the 1990's. (From Crow and Quayle, 2000).

Many of the regional climate change findings over the past five to ten years can be summarized as followings (Crowe and Quayle, 2000):

- Temperatures are increasing.
- Regional temperature changes are several times larger than the global average:

Daily minimum temperatures are increasing at twice the rate of maximum temperatures and several times the rate of the global temperature increase.

Increase in the minimum temperature is 1.5°F since 1950 and is 0.7°F for maximum temperature.

- There is evidence for an enhanced hydrologic cycle:
 - Decrease in daily temperature range
 - More atmospheric water vapor
 - More precipitation
 - More intense precipitation events
 - Stronger extratropical storms
- There is no evidence for changes in hurricane frequency or intensity.

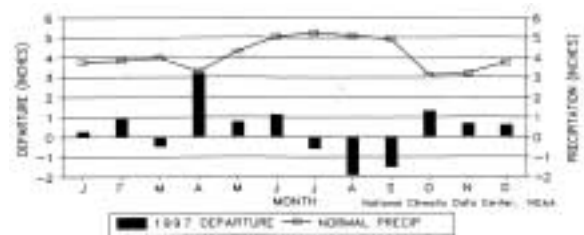


Figure 10. Gulf Coast region precipitation. Precipitation departures for 1997 from 1961-90 normals. The last three months wetness is consistent with El Niño projections. (From Crow and Quayle 2000).

The most serious consequence of climate change during the past Century for the Gulf Coast environments is sea-level rise. Much of the apparent rise in sea-levels is in response to melting of glacial and polar ice and thermal expansion of warmer oceans (Muller and Grymes in Ning et al., 2000). The historical data suggest sea-level rise of about 12 cm (5 inches) during the last 100 years. It must be stressed that for the Gulf Coast region these are very conservative estimates of local sea level “rise,” as continued deltaic and coastal subsidence is likely to significantly enhance the apparent sea-level rise above global projections.

Sea-level rise has already had significant impacts on coastal areas and these impacts are very likely to increase (NAST 2000). Between 1985 and 1995, southeastern states lost more than 32,000 acres of coastal salt marsh due to a combination of human development activities, sea-level rise, natural subsidence, and erosion. About 35 square miles of coastal land were lost each year in Louisiana alone from 1978 to 1990.

Along with the change and variability in temperature and precipitation, the Gulf Coast region has also experienced change and variability in extreme weather events. For the past

10-20 years, this region has experienced high frequency of weather related extreme events and disasters. The data of 1980-2000 (US Census Bureau, Statistical Abstracts 2001) indicated that of the total of 46 weather related extreme events and disasters that occurred in the US, 16 of them (34%) occurred in the Gulf Coast region, with 6 hurricanes, 4 floods, 3 drought/heat waves, 2 tornados, and 1 tropical storm (Figures. 11a and b).

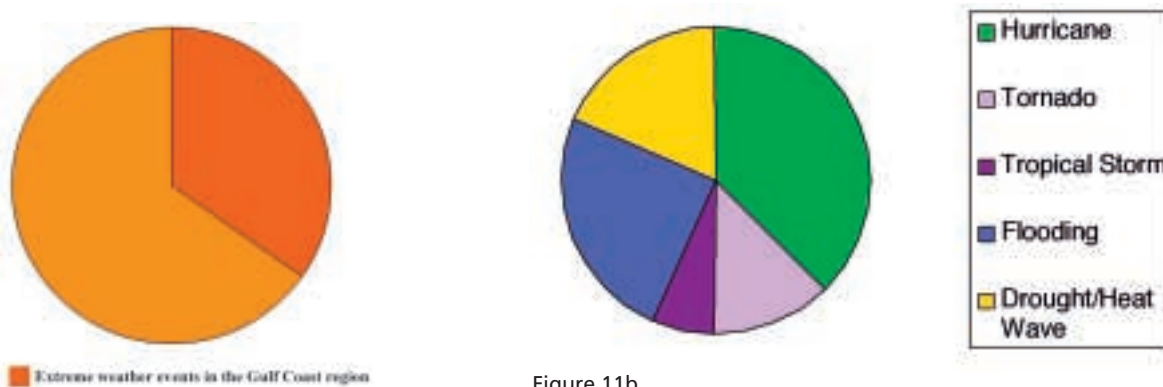


Figure 11a

Extreme weather events in the Gulf Coast region

Figure 11b

Figure 11. Extreme weather events and disasters in the Gulf Coast region for the past 20 years. **11a.** Among all extreme weather events in US, 34% of them occurred in the Gulf Coast Region. **11b.** Types and frequencies of the extreme weather events in the Gulf Coast region. Based on the data from US Census Bureau, Statistic Abstracts 2001.

1.2.3 Future Climate Scenarios

Climate model projections exhibit a wide range of plausible scenarios for both temperature and precipitation over the next century. Both of the principal climate models used in the National Assessment project warming in the Gulf Coast by the 2090s, but at different rates (NAST, 2002). The Canadian model scenario shows the Southeast including the Gulf Coast region experiencing a high degree of warming, which translates into lower soil moisture as higher temperatures increase evaporation. The Hadley model scenario simulates less warming and a significant increase in precipitation (about 20%). Some climate models suggest that rainfall associated with El Niño and the intensity of droughts during La Niña phases will be intensified as atmospheric CO₂ increases (Figure 12 and 13).

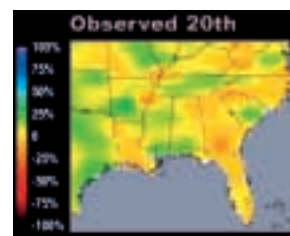


Figure 12. Scenario of the future temperature in the region. Model scenarios project relatively uniform increases in annually averaged temperatures. However, the Canadian model projects increases that are twice as large as the Hadley model. From NAST, 2000.

The Hadley model predicts an average sea-level rise of 8.4 inches over next 100 years in the Gulf Coast region while the Canadian model predicts 15.6 to 19.2 inches. Coastal ecosystems and the services they provide to human society are likely to be negatively affected by sea level rise (NAST 2000). Projected impacts are likely to include the loss of barrier islands and wetlands that protect coastal communities and ecosystems from storm surges, reduced fisheries productivity as coastal marshes and submerged grass beds are displaced or eliminated, and saltwater intrusion into surface and ground water supplies. The

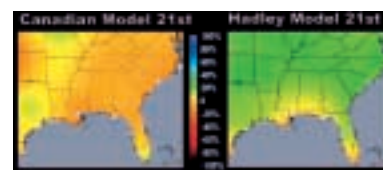


Figure 13. Scenario of the future precipitation in the region. The Canadian model scenario for the 21st century indicates near neutral trends or modest increases, while the Hadley model projects increases of near 25% for the region. From NAST, 2000.

impact of sea-level rise on coastal ecosystem will depend upon the rate of rise and the development that has occurred along the shoreline. Other threats to these ecosystems come from changes in rainfall in coastal watersheds which are likely to alter fresh water inflows into estuaries, altering salinity patterns that determine the type and distribution of coastal plant and animal communities. There are few practical options for protecting natural ecosystems as a whole from increasing temperature, changes in precipitation, or rapidly rising sea level.

• REFERENCES •

- Crow, M. and R. G. Quayle 2000. Observed climate trends for the globe and the southeastern United States. In Current Stress and Potential Vulnerability-Implications of Global Climate Change for the Gulf Coast Region. Ed. Ning, Z. H. and K. K Abdollahi, GCRCC and Franklin Press, Baton Rouge, LA*
- Duncan, F., M. McGregor, and D. A. Thompson 1995. Geomorphology and Land Management in Changing Environment.*
- Easterling, D. R., T. R. Karl, E. H. Mason, P. Y., Hughes, and D. P. Bowman 1996. United States Historical Climatology Network (U.S. HCN). Monthly Temperature and Precipitation Data, Bulletin 4500, NDP-01/R3. Oak Ridge Nat. Lab., Oak Ridge, TN.*
- Karl, T. K., N. Nicholls and J. Gregory 1997. The Coming Climate. Scientific American. 276(5): 78-83.*
- Muller, R. A. and J. M. Grymes 2000. Global climate change from the perspective of the climate record in Louisiana. In Current Stress and Potential Vulnerability-Implications of Global Climate Change for the Gulf Coast Region. Ed. Ning, Z. H. and K. K Abdollahi, GCRCC and Franklin Press, Baton Rouge, LA*
- NAST 2000. Climate Change Impacts on the United States-The Potential Consequences of Climate Variability and Change. Overview by the National Assessment Synthesis Team for the US Global Change Research Program, Cambridge University Press, Cambridge, UK*
- The New Encyclopededia Britannica 1998. 15th Edition, Encyclopedia Britannica, Inc.*
- Ringold, P. L., and J. Clark 1980. The Coastal Almanac. W. H. Freeman, San Francisco.*
- U.S. Census Bureau 2001. Statistical Abstract of the United States: 2001 (119th Edition). Washington, D.C.*
- The World Book Encyclopedia 1998. World Book Inc.*

CHAPTER 2. GULF COAST REGION AND CLIMATE CHANGE: STAKEHOLDERS PERSPECTIVE ON REGIONAL SECTORAL ISSUES



At the 1998 workshop, the participants identified numerous issues of regional concern should climate change as either of the model scenarios project. Coastal ecosystems, forests, water and air quality, fisheries, commerce, industry, and energy, were the key sectors that the participants considered to be vulnerable to climate change. This chapter summarizes the key findings of these key sectors/issues from the workshop. (Ning and Abdollahi, 1999, USGCRP, 1998a). Due to time and resource constraints, not all of these identified issues could be addressed in depth in a follow-up assessment. So the regional assessment research team selected coastal ecosystem and maritime forest resources as two foci for further assessment efforts including case studies. Major findings of the assessment case studies are summarized in chapters 3 and 4.

2.1 Coastal Ecosystems

The potential consequences of climate and other changes are of great practical concern to those interested in the Gulf Coast region's wetland resource. The wetland in the Northern portion of the Gulf Coast area are of greatest risk because of the low-laying habitats with easily eroded substrates. The IPCC and the World Meteorological Organization (IPCC, 1997 and WHO, 1996) have identified coastal wetlands as an ecosystem most vulnerable to direct, large-scale impacts of climate change, primarily because of their sensitivity to increases in sea-level rise.

The Gulf Coast is a region prone to rapid subsidence of an order of magnitude greater than the Atlantic and Pacific coastal zones. The Governor of Louisiana's representative at the Workshop referred to this region as the "Poster Child of Vulnerability." Accelerated sea-level rise of any predicted rate, high or low, will only exacerbate the impacts of the existing rate of sea-level rise on this highly vulnerable coastal region.

The Gulf Coast ecosystems are already impacted by stresses of altered watershed dynamics and flood control measures. Changing climate conditions that impact flow regimes in other regions (such as the Upper Mississippi River watershed) are also felt along the Gulf Coast. The Gulf Coast states have experienced an increase in total annual rainfall during this century. This increase is associated with more intense rainfall events, which alter both the timing and delivery of freshwater to coastal wetlands and estuaries. The State Climatologist for Louisiana stated that intense spring rainfall events have doubled in frequency since 1971, while the number of summer rainfall events during that period were half as frequent. In addition to these climatic changes, flood control measures and impoundment alter surface water flows and impede the sediment flux that is necessary to sustain the development of river deltas. The extraction of freshwater for municipal purposes and irrigation, along with landscape fragmentation in the coastal zone have altered the balance of freshwater and tidal flows. Several Gulf Coast estuaries and wetlands are slated for engineered restorations, e.g. fresh water diversions along the lower Mississippi River and the Everglade's surface water restoration.

Rising sea level and deteriorating landforms allow saltwater to intrude continually further inland and to mix with surface and groundwater supplies. Changing the salinity patterns of Gulf Coast wetlands threatens the stability of freshwater ecosystems and survival of two important shellfish resources — oysters and shrimp. Fertilizers, herbicides, and pesticides applied on agricultural crops in watersheds that feed coastal marshes and estuaries also pose a real concern. The cumulative impact of water removal and replacement, whether for municipal or industrial purposes, involves a reduction in the quality of water entering downstream wetlands. Urban floodwaters that are pumped across levees also introduce significant contaminants of unknown fate into adjoining wetlands.

Frontal passages and hurricanes account for most of the acute effects that lead to coastal changes of barrier islands and wetlands. Even relatively mild winter storms create fetch dynamics in coastal bays and estuaries that can cause significant impacts.

The invasion of non-indigenous species of flora and fauna alters the structure and balance of coastal systems to the exclusion, in some cases, of native species. The loss of habitat for resident wildlife is also of concern. The Gulf Coast spans the transition zone between temperate and sub-tropical climates and species distribution, this enhances the biological diversity of the region. Climate changes and conditions may foster the rate of spread of exotic species. Some notable exotic species that are problems in the area already include: Melaleuca, Salvinia, water hyacinth, Eurasian millfoil, Brazilian pepper, Chinese tallow tree, gecko, and zebra mussel.

Alabama

Alabama is located at the intersection of several geographic areas, and its ancient and complex geological terrain is home to a variety of ecosystems, ranging from the Appalachians in the north to the coastal plain in the south. Although it ranks 29th of all the states in area, it is the nation's fourth in terms of plant and animal species richness. With 235,000 miles of waterways spanning three major river basins (the Mobile, Tennessee, and Apalachicola), its aquatic biodiversity is particularly notable. The freshwater fauna in the rivers and streams include 52% of North America's known freshwater turtles (of these, 22% are endemic to the state), 38% (41% endemic) of freshwater fishes, 60% (34% endemic) of freshwater mussels, and 43% (77% endemic) of all gill-breathing snails. The Cahaba River, Alabama's longest free-flowing river, is home to 131 species of fish, the greatest diversity for any river of its size on the continent. Alabama's coastline may be small in comparison to other Gulf Coast States, but over 500 species of marine mollusks have been found in the coastal sands and waters of Alabama. Climate Changes could exacerbate threats to coastal and freshwater ecosystems. Warmer air temperatures could lead to reduced stream flow and warmer water temperatures, which would significantly impair reproduction of fish and other animals and favor the spread of exotic species that exhibit a high tolerance for extremes environmental conditions. Habitat for warm water fish could be reduced by hotter temperatures. The low-lying Mississippi Delta is particularly vulnerable to the effects of sea level rise – inundation of coastal lands, intrusion of saltwater into coastal freshwater ecosystems, and increases in erosion rates and storm damage resulting from increase storm frequency. If rainfall increases, runoff along the Gulf Coast and the rate of estuarine flushing are expected to increase, leading to reduced yields in shrimp and other species favoring high salinities. Higher runoff rates and outflow into the Gulf of Mexico could increase nutrient loads and alter water temperatures, exacerbating the already serious eutrophication and hypoxia.

Florida

Southern Florida has natural national treasures in the Big Cypress Swamp, the Everglades, and the Keys. These three ecosystems are inter-twined and have a common history. The Big Cypress Swamp is part of the broad, shallow river moving fresh water south into the Everglades. The Keys mark the last outposts of the Everglades lands. Once hummocks of higher vegetation set in a prehistoric swamp, they have maintained themselves against the rising sea. Mangroves on their perimeters collect silt and organic material, building a barricade secure against all but the most severe hurricane winds and tides. In the Everglades and Big Cypress Swamps, there is a strong contrast between the seasons. From early spring well into autumn, they have ample rainfall, averaging 50 inches per year. Winter is a time of drought and fire, and saltwater penetrates farther inland.

Already stressed by water diversions, non-native species of plants and animals, and the natural phenomena of drought, flood, and storms, these ecosystems will be stressed further by climate change. A 20-inch sea level rise would cause large losses of mangroves in southwest Florida. Increase salinity, resulting from rising saltwater into the Everglades from Florida Bay, also would damage freshwater ecosystems containing sawgrass and slough. Communities of wet prairie also would decline with the rise in sea level. Climatic conditions in central Florida may become suitable for subtropical species such as Gumbo-limbo, now confined to subtropical hummocks in the southern part of the peninsula and the Keys. Theoretically, under projected climate change, such species could be found as far north as Gainesville and Jacksonville, but agricultural and urban development will likely preclude such a progression.

Louisiana

Louisiana's Mississippi river delta contains the largest area of wetlands in the nation. These coastal wetlands support 30% of national commercial fish and shellfish harvests. They are also the winter home of 20-25% of the ducks that frequent ponds in North America. These wetlands are among the most commercially and ecologically productive in the United States. The coastal marshes in Louisiana generate over \$2 billion worth of commercial species such as oysters, crabs, fish and shrimp each year. They also are an invaluable buffer against storm surges.

Louisiana is already losing many of its wetlands because levees and other structures along the Mississippi River prevent soil accumulation. Sea level rise most likely will accelerate wetland loss, which will reduce important habitats for migratory birds, crayfish, sport fish, and other species. Some warm water fish species such as black crappie could lose all of their habitat in Louisiana as a result of the effects of climate change. In addition, spotted sea trout, oyster larvae, pinfish, and flounder would lose much, if not all, of their habitat.

Mississippi

Most of Mississippi is made up of habitats associated with either the coastal plain or the Mississippi Delta. The coastline is separated from the Gulf of Mexico by a shallow sound and is paralleled by a series of barrier islands. The Mississippi flatlands in the alluvial plain attract hundreds of thousands of migrating snow geese, Canada geese, and ducks in the winter. Wetlands play a major role in basin hydrology and serve as wildlife habitats.

The low-lying Mississippi Delta is particularly vulnerable to the effects of sea-level rise—inundation of coastal lands, intrusion of saltwater into coastal freshwater ecosystems, increase in erosion rates and storm damage with increasing wave force and storm

frequency. If runoff along the Gulf Coast increases, estuarine flushing rates would increase, leading to reduced yields in shrimp and other species favoring high salinities. Increasing runoff rates and outflow into the Gulf of Mexico could increase nutrient loads and alter water temperatures, exacerbating already serious eutrophication and low oxygen levels. Loss of coastal wetlands and marshes with rapid sea level rise would reduce estuarine health because many estuarine species depend on wetlands as nursery areas and source of organic matter.

Texas

The coastal wetlands, which support important fisheries and provide vital wildlife habitat, are also vulnerable to climate change. For example, Brazoria National Wildlife Refuge, a 43,388 acre coastal estuarine and coastal prairie habitat on the Gulf Coast, provides winter habitat for 30,000–40,000 ducks and 40,000 snow geese. The refuge also contains about 4,000 acres of native coastal systems. Sea level rise would accelerate loss of wetlands and estuaries, eliminating breeding and foraging habitat for commercial, game, and threatened and endangered species.

The vast area within Texas includes a great diversity of ecosystems, from forests to grasslands to semiarid shrublands to extensive coastal and inland wetlands. In land-based Texas, climate change could weaken and stress trees, making them more susceptible to pine bark beetle outbreaks. Semi-arid grasslands and shrublands are very sensitive to changes in rainfall season and in the amount of rainfall, and could be affected adversely by warmer, drier conditions.

2.2 Forests

Climate variability is already a prime stress on forests of the Gulf Coast region and is related to the many summer storms of both sub-tropical and convection driven origin. Forests are affected by numerous thunderstorms of high intensity as well as tropical storms and the associated high winds. The high rainfall during short periods associated with these storm leads to flooding and waterlogged soils. Plant growth is impacted. Reduced root growth and increased incidence of windthrow are not uncommon problems.

Along the coast and for some distance inland, sea-level rise is a major problem in the region. Natural sea-level rise is a product of warming temperatures and thermal expansion. Apparent sea-level rise is influenced by subsidence caused from the compaction of organic soils and the losses of sediment influx as drainage patterns have been altered in coastal areas. Sea-level rise reduces drainage of rivers and streams resulting in flooding. Sea-level rise can also increase saltwater intrusion that can significantly alter the coastal ecosystems and coastal aquifers. Freshwater swamps are being stressed by saltwater intrusion and bottomland hardwoods are being killed by alteration of flood timing and duration. Changes in species composition, changes in wetland boundaries, and complete loss of terrestrial ecosystems to open water areas have occurred. Such changes have also been associated with increased numbers of pests and success of new pests in the region.

Although high rainfall is common, the Gulf Coast region also experiences its share of droughts. Droughts in recent years have caused much damage and loss of productivity. Plants growing in waterlogged soils have restricted root systems and once the soils begin to dry out, plants are unable to extract sufficient water from the soil. Wildland ecosystems

under water stress often lead to insect and disease infestations, with a concomitant increase in the frequency and severity of wildfires. The release of sequestered carbon through uncontrolled wildfire can lead to major air pollution and to the buildup of radiatively important gases and particles in the atmosphere. In the summer, high temperatures provide additional stress through increased plant respiration, reduced photosynthesis, and direct-heat-caused injury. In the winter, temperature fluctuation and the sudden onset of freezing temperatures result in biological miscues and loss of productivity. The negative impacts on flower and fruit production are most noticeable.

Ozone and other air pollutants are problems in many areas of the Gulf Coast region. Foliar damage, reductions in photosynthesis, and associated reductions in growth have been shown to occur as a result of air pollution. These problems are becoming more serious in the Gulf Coast region as temperature increase.

Alabama

In Alabama, longleaf and slash pine forests could expand northward and replace some of the loblolly and shortleaf pine forests. Wetter conditions would favor expansion of southern pine forests, as well as oak and hickory forests and the gum and cypress forests found along the Gulf Coast. In contrast, under drier conditions, 40-70% of forests in the east-central part of the state could be replaced by grasslands and pasture. Warmer and drier conditions could increase the frequency and intensity of fires, which could result in increased losses to important commercial timber areas. Even warmer and wetter conditions could stress forests by increasing the winter survival of insect pests.

Florida

The mixed conifer/hardwood forests found in the northern and panhandle sections of Florida are likely to retreat northward. These forests eventually could give way to wet tropical forests such as tropical evergreen broadleaf forests and dry tropical savanna. These changes would be accompanied by a reduction in forest density. The dry tropical savanna of the Florida peninsula could become more of a seasonal tropical forest with a corresponding increase in forest density. The potential dieback of forests along the Gulf coast could adversely affect forest-based recreation and commercial timber.

Louisiana

With changes in climate, the extent and density of forested areas in Louisiana could change little or decline by 5-15%. Hotter, drier weather could increase wildfires, particularly in the important timber producing regions in the northern part of the state. In some areas, the types of trees dominating Louisiana forests are likely to change. Longleaf and slash pine densities could increase, as would the extent of cypress and gum dominated forests in southeastern Louisiana. Loblolly and shortleaf pines would continue to thrive over much of the state; however, drier conditions could result in increased areas of grassland and savanna in the western part of the state.

Mississippi

About 55% of the land area of Mississippi is covered with forests, including bottomland hardwoods, pine woods, and oak-hickory forests. In Mississippi, longleaf and slash pine forests could expand northward and replace loblolly and shortleaf pine forests if the climate changes as predicted. Wetter conditions would favor expansion of southern pine forests as well as oak and hickory forests and the gum and cypress forests found along the Gulf Coast. In contrast, under drier conditions, 50-75% of forests in the east-central part of the state could be replaced by grasslands and pasture.

Texas

With changes in climate, the extent and density of forested areas in east Texas could change little or decline by 50-70%. Hotter, drier weather could increase wildfires and the susceptibility of pine forests to pine bark beetles and other pests, which would reduce forests and expand grasslands and arid shrublands. With increased rainfall, however, these effects could be less severe. In some areas, the types of trees dominating Texas forests would change, for example, longleaf and slash pine densities could increase in the deciduous forests of east Texas.

2.3 Water and Air Quality

The Gulf Coast shares a number of stresses that are currently creating problems for coastal areas due to a high rate of population influx and development along the coast. Many of the human health stresses in the region relate to contamination of the marine and aquatic or fresh water environment as a result of development, agriculture (nitrogen flow), and industrial pollution, such as benzene and other organic chemicals from oil refining. The Gulf Coast has the highest concentration of petrochemical companies in the nation. With the potential of sea-level rise, coastally located infrastructure is at risk and thus, has the potential for increase in water pollution. Fresh water contributions to regional water pollution are also of concern. For example, the Mississippi River carries the chemical pollutants of the Central U.S. to the Gulf Coast region. The extraction, refining, and transport of oil and petrochemicals all carry risks for the health of humans, wildlife and ecosystems. Extreme rains and flooding can enhance run-off of nutrients, pollutants and microorganisms. Heavy rains and high nutrient levels can increase algae blooms and add to the “hypoxic zone” in the Gulf of Mexico, currently the size of New Jersey.

The growth of cities and the effects of this growth on air quality are health concerns in the Gulf Coast region. Large cities such as Houston and New Orleans already have significant problems with air pollution, particularly tropospheric ozone (O₃). Pollution stagnation, such as occurred in Baton Rouge in 1990 and 1995, is dangerous to those who have already have respiratory problems and may be exacerbated by increased temperatures. Poor air quality contributes to reach health endpoints such as heat shock, asthma, respiratory disease, and allergies.

In fact, there were a number of climate related disease events in Florida in 1997 that affected both humans and plants. These included St. Louis encephalitis around Orlando and three crop pests: medfly in Dade county, citrus canker sore and tomato leaf virus carried by whiteflies.

When air quality is poor, people often stay inside and are then subject to indoor issues. In addition, when temperatures increase, more people use air conditioners, adding to the pollution problems.

Increasing water demand to supply the growing populations in large cities is a potential threat to the availability of clean water in the Gulf Coast region. The large population growth in Atlanta is currently being viewed as a problem for Gulf Coast water quality. Similarly, population growth and the diversion of water are also problem for the water quality of the Rio Grande River. To assess this problem, it is important to monitor key water systems and to determine the purpose for which water is being used.

Alabama

In a warmer climate, runoff is likely to be reduced primarily because of higher temperatures, increased evaporations, and changes in precipitation. Reduced runoff and the resulting lower groundwater levels, especially in the summer, could affect the availability of water to satisfy the Gulf Coast's growing and competing needs for municipal, industrial, irrigation, and recreational uses of water. Large groundwater withdrawals in the coastal zones of Baldwin and Mobile counties, which include the Mobile Bay and Gulf Shores regions, have resulted in increased salinity in wells because when freshwater is drawn down saltwater can then intrude into the aquifers. An increase in sinkhole formation has also been associated with large groundwater withdrawals. Should warmer and drier conditions occur, particularly if accompanied by rising sea levels, they could compound the problems of high demand for water and low availability. Lower water levels and higher temperatures could also impact water quality by concentrating pollutants.

Florida

A critical factor in Florida's development, especially in southern Florida, has been water. Competing demands for water – for residences, agriculture, and the Everglades and other natural areas – are placing stresses on south Florida's water resources. Although south Florida receives an annual average of 60 inches of rain, annual evaporation sometimes can exceed this amount. Rainfall variability from year to year is also high, resulting in periodic droughts and floods. Higher temperatures increase evaporation, which could reduce water supplies, particularly in the summer. Saltwater intrusion from sea level rise also could threaten aquifers used for urban water supplies. These changes could further stress south Florida's water resources.

Louisiana

Most of Louisiana drains to the lower Mississippi and Red rivers, both of which have headwaters thousands of miles from their mouths. Stream flow in these rivers is affected mostly by conditions outside Louisiana's borders. Because much of the runoff of the Red and Mississippi rivers comes from areas where there is little snowfall, stream flow is affected by changes in precipitation and temperature. Summer flows of these rivers could be reduced by the increased evaporation that would occur in a warmer climate. The part of Louisiana that is not in the Red or Mississippi river basins is drained by smaller rivers and streams that flow directly to the Gulf of Mexico.

Mississippi

Declining groundwater levels are a matter of concern throughout the state. Increased rice irrigation and fish farming in the northwestern Delta region have reduced groundwater levels in the Mississippi alluvial aquifer. Increased municipal and industrial withdrawals in the metropolitan Jackson area, along the Gulf Coast, and in northeastern Mississippi also have lowered groundwater levels. Additionally, in the southern half of the state, saline water has begun to intrude into freshwater aquifers because of declining groundwater levels along the coast as well as from saline waste water injection into oil-field production zones. Warmer and drier conditions, particularly if accompanied by sea-level rise, could compound these types of problems due to higher water demand and lower flows.

Warmer temperatures could lead to reduce stream flow and warmer water temperatures, which would significantly impair reproduction of fish and other animals and favor the spread of exotic species that exhibit a high tolerance for extreme environmental conditions.

Texas

Several major river basins lie in part, or entirely, within Texas. Most of the state is drained by several south-flowing rivers, including the Neches, Trinity, Brazos, Colorado, San Antonio, and Nueces. Western Texas drains into the Rio Grande or its major tributary, the Pecos River. Unless increased temperatures are coupled with a strong increase in rainfall, water could become more scarce. A warmer and dryer climate would lead to greater evaporation, as much as a 35% decrease in streamflow, and less water for recharging groundwater aquifers. Increased rainfall could mitigate these effects, but also could contribute to localized flooding. Additionally, climate change could give rise to more frequent and intense rainfall, resulting in flash flooding.

2.4 Fisheries

Coastal habitat quality is affected by factors like industrial and metropolitan development along the coastal zone, tourism and recreation, inland land use (natural vegetation cover versus agriculture or silviculture, fertilizer and pesticide use, animal husbandry, etc.), and atmospheric and hydrologic deposition of pollutants (e.g., inorganic nitrogen) from industry located far inland. The extent to which climate change will exacerbate or ameliorate stresses on fisheries associated with changes in coastal water and habitat quality depends on future trends of coastal zone development. Some sense of the minimum amount of undisturbed coastal habitat and minimally disturbed coastal habitat buffer needed to sustain current fisheries must be gained in order to project habitat needs under climate change scenarios.

Increased variability in precipitation has the potential to greatly impact coastal fisheries by affecting freshwater inflow to estuaries, which in turn would affect flushing rates, the location of the freshwater-saltwater interface, and the quality of coastal estuarine nursery areas for fish and shellfish. Further inland, increased variability in precipitation has the potential to negatively impact riverine fish resources.

Fishermen of the Terrebonne Fishermen's Organization expressed concerns about coastal erosion and the loss of coastal marsh habitat, which, in Louisiana, is mainly attributable to subsidence of deltaic deposits of the Mississippi River, and human alteration of coastal marsh. They are concerned that sea level changes associated with global climate change will exacerbate the current problems of coastal erosion. Even small rates of sea-level rise take on a special significance in coastal Louisiana.

In 1997 Louisiana fisheries contributed roughly \$20 billion to the gross national product, employing about a million people. Marsh and other coastal habitats on which coastal fisheries depend play an important role as nursery grounds for many commercially important fish and shellfish species. Other commercially important fishes, whose life histories are not directly tied to coastal habitats, are dependent on fish and shellfish produced in coastal habitats.

All aquatic organisms have particular ranges of physiological tolerance to factors like temperature, salinity, pH and dissolved oxygen. In general, species are found only in habitats that meet all of their requirements for survival, growth, and reproduction. These requirements often differ with different life history stages (eggs, larvae, and adults), particularly in marine and estuarine species. A change to warmer water temperature in the Gulf of Mexico, for example, has the potential to restrict the zone of inhabitation of temperate

adapted species (northward movement in the Northern Gulf of Mexico is limited by the coastline) and shift the zone of more tropical adapted species northward.

The same may be said for fishes in inland freshwater stream and lake habitats along the Gulf Coast. The species are generally temperature adapted, so any warming, or tendency toward warmer extremes than at present, has the potential to restrict their natural range. The ability of any of these species to migrate north or south is dependent on the range of stream sizes the species normally inhabits, and the presence of barriers to dispersal such as dams or natural physiographic features.

A critical problem in trying to predict how global climate change might impact populations of both coastal and inland fisheries is that very little is known about the specific tolerances and life history requirements of many of the species involved. Life history information is being gathered for many of the commercially important species by agencies such as the National Marine Fisheries Service and state fisheries departments. However, the information need to be gathered in a coordinated way, with a view toward future climate change. In cases where key life history information is being gathered (e.g., in the course of routine shrimp, ichthyoplankton and groundfish surveys), important information on conditions of capture need to be recorded or archived, the collections need to be precisely referenced as to geographic position, and the collections need to be archived. We need a comprehensive interagency review of information needs related to impacts of global climate change on coastal fisheries, a better coordination of ongoing fishery surveys with proper attention to the quality of the information being gathered, and improved databasing and archiving of information collected.

2.5 Commerce, Industry and Energy

Industries of the region can be divided into two broad categories: primary industries and support industries. Primary industries with the most impact on the economies of the Gulf Coast region (in no particular order) are oil and gas, agriculture and forestry, tourism and entertainment, fisheries and aquaculture, chemical, manufacturing, port transfer and shipping. A number of support industries with important roles in the region (in no particular order) are insurance, finance, real estate, construction, medical and health, public sectors, military, government, and retail.

Current climatic and non-climatic stresses can be related to the relevant industries. Some of these influences originate within the region, while others have global dynamics. Some general "stresses" are coastal land loss, saltwater intrusion, population growth, and education/training of the general population and available workforce. Specific effects on the primary industries include the following:

- a. Oil and gas:** Clearly, global energy markets, international emissions agreements, and national policy are major forces in shaping the demand for oil and gas products, and the ultimate mix of fuels used to meet the nation's energy needs. Also, the current age and inefficiency of capital equipment is an important stress in this industry as well as in the chemical and manufacturing industries. Weather plays a substantial role in determining demand for, hence the price of, various fuels. Another major stress on the oil and gas industries is the frequency and magnitude of major storms. In such cases, drilling activities in the Gulf are curtailed. While this stress is currently thought to play only a minor role, future increases in storm intensity and frequency associated with climatic change could be important.

- b. Agriculture and forestry:** Agriculture is particularly sensitive to climate variability and extremes. The dates of the first and last frosts dictate planting and harvesting schedules. Shifts in the length of growing season can benefit or harm agriculture. Some crops will likely benefit from the enhanced CO₂ and increased air temperatures. There may even be opportunities for double cropping (i.e., two growing seasons each year). The expected drying of the soil and increased magnitude of heavy precipitation events, on the other hand, may be damaging to the agricultural industry.
- c. Tourism and entertainment:** Weather in the Gulf Coast region has an important influence on tourism. For instance, it is generally known that the month of August can be quite hot and humid, discouraging tourists and encouraging residents to travel out of the region. The role of weather in tourism, however, is a two-way street. Many of the tourists visiting the region in winter months are from the northeast. If winters in the northeast are less severe, there will be less incentive for these individuals to flee to the south. Another important influence on tourism is the perception of health threats. One example is the recent outbreak of encephalitis in central Florida, that resulted in the evening closings of the Disneyworld parks. Even very small outbreaks of infectious disease can have major impacts on tourism.
- d. Fisheries and aquaculture:** Wetland loss is a current issue of great importance to the fisheries and aquaculture industries. If natural subsidence is enhanced by sea-level rise, these industries may be severely impacted. There are also salinity issues associated with the interface between the coastal salt water and the brackish and fresh water marshes.
- e. Chemical:** While the chemical industry is generally not significantly impacted by climate, it relies on the oil and gas industries for much of its raw materials, and is also subject to the policy actions of local governments which often act to limit emissions. Environmental activism is also playing a more pronounced role, as the activist groups grow and become more vocal about their environmental concerns. Vocal public opposition to the proposed Shintech PVC plastics plant in Louisiana is one of the examples.
- f. Port transfer and shipping:** This industry depends upon port access that in some cases may be affected by river flow rates, sedimentation, and the need for dredging. Ship traffic can also be significantly impacted by severe storms.

2.6 Climate Change and Sea - Level Rise

Rising global temperatures are expected to raise sea-level, and change precipitation and other local climate conditions. There are five major physical impacts of sea-level rise: (1) erosion; (2) inundation; (3) salinization; (4) increased flooding and storm damage; and (5) rising water tables (Nicholls et al., 1994). Sea-level rise does not act in isolation and the impacts can be offset or reinforced by other factors such as sediment availability, or changing freshwater runoff. The coastal zone will also evolve due to processes other than sea-level rise. Therefore, when examining potential impacts of sea-level rise for planning purposes, it is important to consider all coastal processes (Stive et al., 1990). Rising sea level is gradually inundating wetlands and lowlands; eroding beaches; exacerbating coastal flooding; threatening coastal structures; raising water tables; and increasing the salinity of rivers, bays, and aquifers (Barth and Titus, 1984). The area along the Gulf of Mexico is one of the most vulnerable in the U.S. to rising seas.

Coastal marshes and swamps generally are found between the highest tide of the year and mean sea level. Coastal wetlands provide important habitat and nourishment for a large

number of birds and fish found in coastal areas. Wetland accretion generally has kept pace with the historic rate of sea-level rise (Kaye and Barghoorn, 1964). If sea level rises more rapidly than wetlands can accrete, however, there will be a substantial net loss of wetlands (Titus, 1986; Park et al., 1989).

Coastal development is likely to increase the vulnerability of wetlands to rising sea-level. In many areas, development will prevent the wetland creation that otherwise would result from the gradual inundation of areas that are barely above today's high-water level (Titus, 1986, 1988). In Louisiana, flood control levees, navigation infrastructure, and other human activities have disabled the natural processes by which the Mississippi delta otherwise could keep pace with rising relative sea level; as a result, Louisiana currently is losing about 90 km² (35 mi²) of wetlands per year (Gagliano et al., 1981; Penland et al., 1997).

Louisiana is expected to experience the greatest wetland loss from rising sea-level, compared to other coastal regions and states in the US (Table 1), although most of these losses

Table 1
Regional and national wetland losses in the U.S. for the 1 m global sea-level rise scenarios (% loss of current area).

Region	Current Wetland Area		1 m Shore Protection Policy		
	(mi ²)	Trend	Total ^a	Developed ^a	None ^a
Northeast	600	7	16	10	1 ^d
Mid-Atlantic	746	-5	70	46	38
South Atlantic	3,814	-2	64	44	40
South/Gulf					
Coast of Florida	1,869	-8	44	8d	7 ^d
Louisiana ^b	4,835	52	85	85	85
Florida Panhandle					
Alabama					
Mississippi and Texas	1,218	22	85	77	75
West Coast ^c	64	-111	56	-688	-809
United States	13,145	17	66	49	50
<i>Confidence</i>					
<i>Intervals for US</i>					
95% Low	-	9	50	29	26
95% High	-	25	82	69	66

a, The total scenario implies that all shorelines are protected with structures; hence, as existing wetlands are inundated, no new wetlands are formed. Developed implies that only areas that are currently developed will be protected; "no protection" assumes that no structures will be built to hold back the sea.

b, Evaluation of management options currently contemplated for Louisiana (e.g., restoring natural deltaic processes) was outside the scope of this study.

c, This anomalous result is from small sample size. The impact on nationwide results is small.

d, Results are not statistically significant; sampling error exceeds estimate of wetlands lost.

Source: Titus et al., 1991, and USEPA website at <http://www.epa.gov/globalwarming/publications/reference/ipcc/chp8/america13.html>

are predicted to occur even with the current rate of relative sea-level rise. A 50 cm rise in sea level would cause a net loss of 17-43% of the wetlands, even if no additional bulkheads or dikes are erected to prevent new wetland creation (Titus et al., 1991).

The dry land within 1m above high tide includes forests, farms, low parts of some port cities, communities that sank after they were built and that now are protected with levees, parts of deltas, and the bay sides of barrier islands. Major port cities with low areas include Miami and New Orleans. New Orleans' average elevation is about 2m below sea level.

The most economically important vulnerable areas of the Gulf Coasts are recreational resorts on the coastal barriers-generally long and narrow islands of spits (peninsulas) with ocean on one side and a bay on the other. Typically, the ocean front block is 2-5m above high tide; the bay sides often are 0.5m above high water. Rising sea level tends to cause narrow islands to migrate landward through the overwash process (Leatherman, 1979).

Changing climate generally is increasing the vulnerability of Gulf Coast areas to flooding both because higher sea level raises the flood level from a storm of a given severity and because rainstorms are becoming more severe in many areas. It also is possible that hurricanes could become more intense, thus producing greater storm surges. However, IPCC (1996) concluded that the science currently is inadequate to state whether or not this is likely. Many Gulf Coastal areas currently are protected with levees and seawalls. Because these structures have been designed for current sea level, however, higher storm surges might overtop seawalls, and erosion could undermine them from below (National Research Council, 1987). In areas that are drained artificially, such as New Orleans, the increased need for pumping could exceed current pumping capacity (Titus et al., 1987).

Rising sea level also enables saltwater to penetrate further inland and upstream in rivers, bays, wetlands, and aquifers. Saltwater intrusion would harm some aquatic plants and animals and impact human uses of water. Increased drought severity, where it occurs, would further elevate salinity. Higher salinity can impair both surface and groundwater supplies. If saltwater were able to reach farther upstream in the future, the existing intakes would draw salty water during droughts. As a result, the cypress swamps in Louisiana may become open lakes (Louisiana Wetland Protection Panel, 1987).

Louisiana's coastal wetlands are disappearing at the rate of 25 square miles per year. In the last century, the state of Louisiana lost between 600,000 and 900,000 acres of valuable coastal vegetative wetlands. Estimates reveal that another 600,000 acres will be lost between now and the year 2040. A commitment to establish cost-effective and long-term coastal restoration projects is essential if Louisiana's coastal wetlands are to be saved.

The aquifers that are most vulnerable to rising sea level are those that are recharged in areas that currently are fresh but could become salty in the future. The South Florida Water Management District already spends millions of dollars each year to prevent the aquifer from becoming salty (Miller et al., 1992). A second class of vulnerable aquifers consists of those in barrier islands and other low areas with water tables close to the surface, which could lose their freshwater lens entirely (IPCC, 1990).

Finally, rising sea level tends to make some agricultural lands too saline for cultivation. In areas where shorefront lands are cultivated, the seaward boundary for cultivation often is the point where saltwater penetrates inland far enough to prevent crops from growing. As sea level rises, this boundary penetrates inland-often rendering farmland that is too salty for cultivation long before inundation converts the land to coastal marsh (Toll, 1997).

Alabama

Alabama has a 600-mile tidally influenced shoreline along the Gulf of Mexico. The shoreline consists of a low-lying coastal plain, narrow barrier islands, forested swamps, and low terraces. Along much of the Florida Panhandle and Alabama Gulf Coast, sea level already is rising by approximately 9 inches per century, and it is likely to rise another 20 inches by 2100.

Florida

Along much of the Florida coast, the sea level already is rising 7-9 inches per century. Because of local factors such as land subsidence and groundwater depletion, sea level rise will vary by location. The sea level in this area is likely to rise 18-20 inches by 2100. As sea level rises, coastal areas in Florida, particularly wetlands and lowlands along the Gulf and Atlantic coasts, could be inundated. Adverse impacts in these areas could include loss of land and structures, loss of wildlife habitat, accelerated coastal erosion, exacerbated flooding and increased vulnerability to storm damage, and increased salinity of rivers, bays, and aquifers, which would threaten supplies of fresh water.

Louisiana

At Grand Isle, Louisiana, relative sea level is already rising by 41 inches per century mostly due to land subsidence, and is likely to rise another 55 inches by 2100. Louisiana currently is losing coastal wetlands at a more rapid rate (approximately 25 square miles a year) than any other coastal state or region in the United States. Louisiana's low-lying delta coastal wetlands are a unique case—these wetlands receive large deposits of sediment from the outflow of the Mississippi River.

However, because some of the land surface is subsiding faster than sediment is accumulating. Louisiana wetlands could be flooded extensively even by relatively changes in sea level. A 1-3 foot increase in sea level over the next century is projected to submerge at least 70% of Louisiana's remaining salt marshes. Even freshwater marshes located far inland may convert to brackish or salt marsh.

Mississippi

Mississippi coast has a 360-mile tidally influenced shoreline along the Gulf of Mexico. The shoreline consists of a low-lying coastal plain, narrow barrier islands, and low terraces. At Pass Christian, sea level already is rising by 5 inches per century, and it is likely to rise another 15 inches by 2100. Possible responses to sea level rise include building walls to hold back the sea, allowing the sea to advance and adapting to it, and raising the land and structures (e.g., by replenishing beach sand, elevating houses and infrastructure). Each of these responses will be costly, either in out-of-pocket costs or in land and structures.

Texas

The Texas coastline is over 1,400 miles long. The coastline is composed of wind tidal flats, sandy marshes, salt marshes, and beaches. About 75% of the ducks and geese found in the United States move through the Texas coastal wetlands. The salt marshes provide a home for oysters and clams, and serve as nursery grounds for young shrimp, crab, and fish. These marshes protect the shorelines from erosion and also act as a purification system by filtering out many pollutants added to the waters by human activities. At Galveston, sea level already is rising by 25 inches per century, and it is likely to rise another 38 inches by 2100. Brown shrimp catch in the U.S. Gulf Coast could fall 25% with only a 10-inch rise in sea level.

• REFERENCES •

- Barth, M. C., and J. G. Titus (eds.) 1984. *Greenhouse effect and sea level rise: A challenge for this generation*. Van Nostrand Reinhold Co. Inc., New York, NY, USA, 325 pp
- Gagliano, S. M., K. J. Meyer-Arendt, and K.M. Wicker 1981. *Land loss in the Mississippi River deltaic plain*, *Transactions of the Gulf Coast Association of Geological Societies*, 31: 295-300.
- Intergovernmental Panel on Climate Change (IPCC) 1990 *Climate Change: The IPCC Scientific Assessment*. Houghton, J. T., G. J. Jenkins, and J. J. Ephraums (eds.). Cambridge University Press, New York, NY, USA, and Cambridge, United Kingdom, 365 pp.
- Intergovernmental Panel on Climate Change (IPCC) 1996. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Prepared by IPCC Working Group II. Carter, T. R., M. L. Parry, H. Harasawa, and S. Nishioka (eds.).
- IPCC 1997. *The Regional Impacts of Climate Change: An Assessment of Vulnerability. Summary for Policy Makers*. Watson R. T., Sinyowera M. C., and Moss R. H. eds. Intergovernmental Panel on Climate Change. United Nations Environment Programme.
- Kaye, A., and E. S. Barghoorn 1964. *Lake quaternary sea level change and coastal rise at Boston, MA*. *Geology Society of America Bulletin*, 75: 63-80
- Leatherman, S. P. 1979. *Migration of Assateague Island, Maryland, by inlet and overwash processes*, *Geology*, 7: 104-107.
- Louisiana Wetland Protection Panel. 1987. *Saving Louisiana's coastal wetlands: The need for a long-term plan of action*. U.S. Environmental Protection Agency, EPA-230-02-87-026. 102 pp.
- Ning, Z. H., and K. K. Abdollahi 1999. *Global Climate Change and Its Consequences on the Gulf Coast Region of the United States*. GCRCC, U.S. Federal Building, Baton Rouge, LA 70821-4292, Franklin Press Inc., Baton Rouge, LA 70802.
- Park, R. A., M. S. Treehan, P. W. Mausel, and R. C. Howe 1989. *The effects of sea level rise on U.S. coastal wetlands*. In: *The potential effects of global climate change on the United States: Appendix B— Sea level rise*. Smith, J. B. and D. A. Tirpak (eds.). U.S. Environmental Protection Agency, Washington, DC, USA, 255 pp.
- Penland, G. 1997. *Impact of Weather on Health*. In: *Workshop on the Social and Economic Impacts of Weather*. Pielke, Jr., R.A. (ed.). April 2-4, 1997, Boulder, CO, USA, pp. 87-91.
- Stive, M. J. F; Roelvink, J. A; and H. J. DeVriend 1990. *Large Scale Coastal Evolution Concept*. *Proceedings 22nd Coastal Engineering Conference*, New York.
- Titus, J. G. 1986. *Greenhouse effect, sea level rise, and coastal zone management*. *Coastal Management*, 14(3): 147-171
- Titus, J. G. 1988. *Greenhouse effect, sea level rise, and coastal wetlands*. U.S. Environmental Protection Agency, Washington, DC, USA, 152 pp.
- Titus, J. G. 1991. *Greenhouse effect and coastal wetland policy: How Americans could abandon an area the size of Massachusetts at minimum cost*. *Environmental Management*, 15: 39-58.
- USEPA 1998. *Global Warming – State Impacts*, USEPA National Global Change Research Programs, at <http://www.epa.gov/globalwarming/publications/reference/ipcc/chp8/america13.html>
- USGCRP 1998a. *Gulf Coast Regional Climate Change Workshop Report*, compiled by Zhu H. Ning and the regional assessment team members for the USGCRP, can be found at <http://www.nacc.usgcrp.gov/regions/gulfcoast.html>
- WHO 1996. *Climate Change and Human Health*. WHO/WMO/UNEP: World Health Organization, World Meteorological Organization, United Nations Environment Programme.

CHAPTER 3. COASTAL ECOSYSTEMS: Major Findings of the Coastal Sector Case Studies



- 3.1 Current Status and Stresses
- 3.2 Climate Variability and Change
- 3.3 Response, Coping/Adaptation Options, Information and Research Needs in the Future

3.1 Current Status and Stresses

Coastal ecosystems in the Gulf of Mexico (GOM) are an important national and regional resource because of their many significant ecological functions. They support diverse life forms, including commercially-valuable fisheries species, provide recreational opportunities, storm protection, and are a home for millions of humans. The stressors on coastal resources have continued to increase over the last century under the intertwined pressures of population growth and intensified resource use. Now climate change (temperature, precipitation, changes in run-off and river discharge, sea-level rise, etc.) is an anticipated additional stressor in this century, and with sometimes clear, but often unclear, consequences.

This section provides a brief overview of some of the important ecological aspects of the Gulf of Mexico coastal ecosystems and major (but not all) changes. Subsequent sections discuss four key ecological behaviors that the anticipated future climate changes will likely impact: estuarine salinity, salt marsh sustainability, commercial fisheries (especially shrimp), and low oxygen zones. Each of these is representative of a key aspect of the health of the GOM coastal ecosystems.

There are 31 major estuarine watersheds in the GOM (Figure 1). The Mississippi River and the Atchafalaya River (formed from the Red River and the diverted one-third of the Mississippi River) drain 41% of the US. The other estuaries are largely regional watersheds of much smaller size. The coastal wetland and open water area in the GOM is 28 and 41 % of the US total, respectively (Table 1). Louisiana has 55% of the total wetland area in the GOM, most of which is marsh habitat (Table 2).

Two major habitat changes whose management will be further complicated by the anticipated global climate changes are wetland losses and barrier island erosion. Wetland losses were particularly severe in the northern Gulf of Mexico (Figure 3) due to a variety of human influences, including hydrologic change, eutrophication, and impoundment. In fact, Louisiana's wetland losses, were 69% of the nation's coastal wetland losses from 1978 to 1990. Barrier islands form legal, physical, and hydrological boundaries of importance to both natural and economic worlds. Barrier islands in the GOM are under considerable stress compared to the rest of the US due to either their uses or their physical instability, including retreat (Figure 4).

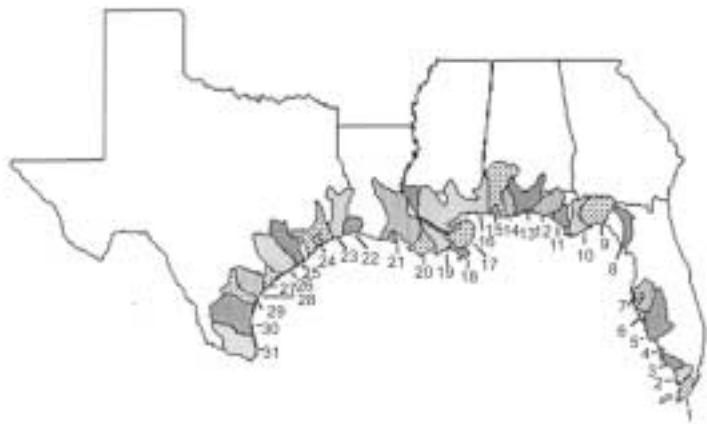


Figure 1. The major coastal watersheds in the Gulf of Mexico.

- | | | | |
|----|----------------------------|-----|----------------------------|
| 1 | Florida Bay | 16. | Mississippi Sound |
| 2 | South Ten Thousand Islands | 17 | Breton/Chandeleur Sounds |
| 3 | North Ten Thousand Islands | 18 | Mississippi River |
| 4 | Rookery Bay | 19 | Barataria Bay |
| 5 | Charlotte Harbor | 20 | Terrebonne/Timbalier Bays |
| 6 | Sarasota Bay | 21 | Atchafalaya/Vermilion Bays |
| 7 | Tampa Bay | 22 | Calcasieu Lake |
| 8 | Suwanee River | 23 | Sabine Lake |
| 9 | Apalachee Bay | 24 | Galveston Bay |
| 10 | Apalachicola Bay | 25 | Brazos River |
| 11 | St. Andrew Bay | 26 | Matagorda Bay |
| 12 | Choctawhatchee Bay | 27 | San Antonio Bay |
| 13 | Pensacola Bay | 28 | Aransas Bay |
| 14 | Perdido Bay | 29 | Corpus Christi Bay |
| 15 | Mobile Bay | 30 | Upper Laguna Madre |
| | | 31 | Lower Laguna Madre |

Estuaries in the southeast/Gulf of Mexico region tend to have lower freshwater turnover times than other US estuaries (Figure 2). The time it takes to turnover the freshwater content of these estuaries could therefore decrease further with climate change. In other words, the flushing rate will increase. Further, some chaotic and episodic climate changes are likely to be introduced, e.g., drought and floods (Knox, 1993). As wetland losses accumulate, then the flushing rates may decrease as open water habitat increases and the estuary deepens. A lower flushing rate (e.g., from increased open water area) might lead to more harmful algal blooms (because of a longer residence time) or higher salinities because of increased seawater mixing through the estuarine mouth. We do not know if these factors will compensate for each other and balance the effects of each so that equilibrium is maintained.

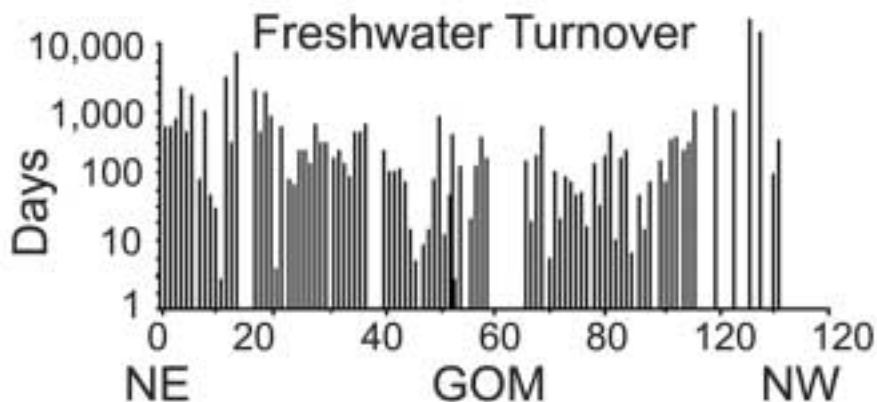


Figure 2. Variations in freshwater turnover times for US estuaries from the Northeast (NE) to the Gulf of Mexico (GOM) to the Northwest (NW). (Adapted from Turner, 2001).

Table 1

Wetland area (km²) and open water area (km²) for 125 major estuaries in the US. From Turner 2001.

Region	Wetland Area (km ²)			Open Water Area (km ²)		
	N	Average (% total)	Range	N	Average (% total)	Range
Northeast	13	252 (4%)	36 - 616	14	395 (7%)	16 - 1419
Middle Atlantic	11	848 (11%)	57 - 4033	21	1103 (28%)	52 - 9920
South Atlantic	17	1399 (28%)	101 - 4579	20	619 (15%)	23 - 7638
Gulf of Mexico	26	1654 (28%)	80 - 8762	35	945 (41%)	5 - 5403
Pacific	14	332 (6%)	5.2 - 2343	33	236 (9%)	3 - 2411
All	81	1079 (100%)	5.2 - 8762	123	666 (100%)	3 - 9920

Table 2

Gulf of Mexico coastal wetland inventory (hectares). From NOAA 1991.

	Marsh	Estuarine scrub-shrub	Forested and scrub-shrub	Total	% Total
Texas	183,900	1,100	3,000	188,000	14
Louisiana	723,500	4,100	1,900	729,500	55
Mississippi	23,800	400	-	24,200	2
Alabama	10,400	1,100	800	12,300	1
Florida	108,100	255,100	13,100	363,900	28
Total	1,049,700	255,100	13,100	1,317,900	100

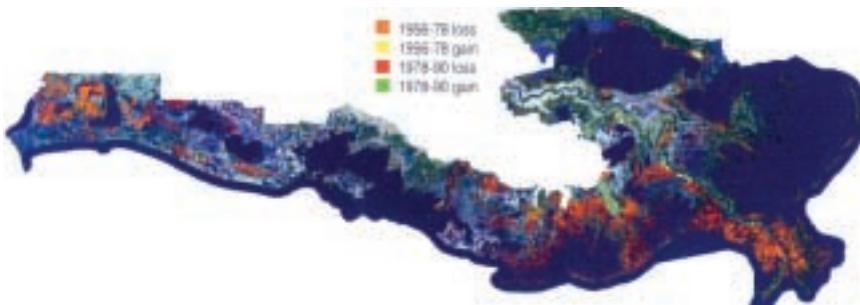


Figure 3. Coastal landloss in Louisiana. From the USGS in Lafayette, Louisiana.

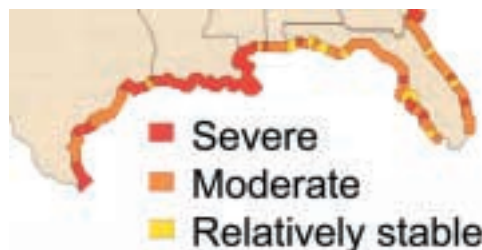


Figure 4. Annual shoreline change in the Gulf of Mexico. Adapted from USGS, 1985.

3.2 Climate Variability and Change

Climate models predict an increase in temperature, variations (higher and lower) in precipitation, and higher riverine flow in major rivers. A summary of the predicted precipitation, temperature, and streamflow changes, by season expected to occur by the year 2100 as a result of global climate changes is in Table 3 (Adapted from Swenson in Ning et al., 2003). The scale of these changes is sufficient to anticipate impacts on the coastal ecosystems, although the magnitude and spatial distribution of impacts is somewhat speculative, given the sometimes conflicting model outputs for regional predictions. This uncertainty is an important area for research attention, since the interpretation of climate change impacts is driven by the magnitude of these changes, some of which might be synergistic, while others might be compensatory.

Table 3

Summary of predicted precipitation, temperature, and streamflow changes, by season expected to occur by the year 2100. The predictions are from the Hadley Model (HadCM2) as summarized by Ning and Addollahi (1999). Adapted from Swenson in Ning et al., 2003.

Season	Parameter	Texas	Louisiana	Mississippi	Alabama	Florida
Winter	Precipitation	5-30% decrease	no change	no change	no change	no change
Spring	Precipitation	10% increase	no change	10% increase	10% increase	no change
Summer	Precipitation	10% increase	10% increase	15% increase	15% increase	no change
Fall	Precipitation	10% increase	10% increase	15% increase	15% increase	no change
Winter	Temperature	4°F increase	<3°F increase	2°F increase	2°F increase	<3-4°F increase
Spring	Temperature	3°F increase	3°F increase	3°F increase	3°F increase	3-4°F increase
Summer	Temperature	4°F increase	3°F increase	2°F increase	2°F increase	3-4°F increase
Fall	Temperature	4°F increase	<3°F increase	4°F increase	4°F increase	3-4°F increase
Winter	Streamflow	35% decrease	unknown	unknown	increase	unknown
Spring	Streamflow	35% decrease	unknown	unknown	increase	unknown
Summer	Streamflow	35% decrease	decrease	decrease	decrease	decrease
Fall	Streamflow	35% decrease	unknown	unknown	unknown	unknown

3.2.1 Estuarine salinity and climate change

Water turnover rates within the estuarine receiving basin will have two important effects on the physical environment of estuaries: the salinity regime will be altered, and the constituents will be diluted. The distribution and magnitude of effects will be indirectly realized through changes in estuarine salinity. For example, higher freshwater inflow will lower estuarine salinity and a lower net precipitation will raise salinities if all other factors remain the same.

Salinity in the northern Gulf of Mexico estuaries is influenced by (1) water exchange between the estuarine entrance and the coastal zone; and (2) local forcing (river discharge, precipitation) occurring within the estuary proper. The Mississippi-Atchafalaya discharge dominates the input in the central portion of the Gulf, while the western (Texas) and eastern (Mississippi to Florida) portions of the Gulf are more heavily influence by local smaller river flows (Table 4). The northern Gulf of Mexico precipitation-evaporation exhibits a gen-

eral decrease in precipitation from east (Florida) to west (Texas), while surface evaporation rates generally increase from east to west across the Gulf. The sum of these two patterns results in an overall precipitation deficit in the western part of the Gulf (and southern Florida) and a precipitation surplus in the central portion of the Gulf.

Table 4

Summary of the major and secondary freshwater sources influencing salinities in the 26 northern Gulf of Mexico estuaries. Adapted from Swenson in Ning et al., 2003.

State	Estuarine system	Major freshwater source	Other freshwater source
Texas	Laguna Madre	Rainfall (65%)	Local riverflow (17%)
Texas	Corpus Christi Bay	Local riverflow (92%)	Rainfall (8%)
Texas	Aransas Bay	Local riverflow (54%)	Rainfall (46%)
Texas	San Antonio Bay	Local riverflow	Rainfall
Texas	Matagorda Bay	Local riverflow (25-80%)	Rainfall
Texas	Brazos River	Local riverflow	
Texas	Galveston Bay	Local riverflow	
Texas	Sabine Lake	Local riverflow	
Louisiana	Calcasieu Lake	Local riverflow	
Louisiana	Mermentau River	Local riverflow	
Louisiana	Atchafalaya/Vermilion	Atchafalaya River flow	
Louisiana	Terrebonne/Timbalier	Mississippi River flow	Rainfall
Louisiana	Barataria Bay	Mississippi River flow	Rainfall
Louisiana	Breton Sound	Mississippi River flow	Pearl River flow
Louisiana	Pontchartrain/Borgne	Local riverflow (90%)	Rainfall (5%)
Mississippi	Mississippi Sound	Local riverflow	Mississippi River flow
Alabama	Mobile Bay	Local riverflow	
Florida	Perdido Bay	Local riverflow	
Florida	Pensacola Bay	Local riverflow	
Florida	Choctawhatchee Bay	Local riverflow	
Florida	St. Andrew Bay	Rainfall	
Florida	Apalachicola Bay	Local riverflow	
Florida	Apalachee Bay	Local riverflow	
Florida	Suwannee River	Local riverflow	Groundwater flow
Florida	Tampa Bay	Local riverflow	Rainfall
Florida	Sarasota Bay	Rainfall	Local riverflow

The results of various climate change model predictions suggest that there will be increases in precipitation on the order of 10% for all of the Gulf states, except Florida. The predicted changes for streamflow are, in most cases, still uncertain. The effect of climate change on Mississippi River discharge is the most important consideration for the Louisiana estuaries, whose salinity is strongly affected by salinity variations in the offshore waters (Figure 5). Boesch et. al., (2000) present data indicating that the Hadley model predicts an increase of ~5%, and the Canadian Model predicts a decrease of ~35% for the Mississippi River discharge from 2025 through 2034. They further state that the Hadley model predicts an increase of ~50%, and the Canadian Model predicts a decrease of ~30% for the Mississippi River discharge from 2000 through 2099, and sea level is predicted to increase on the order

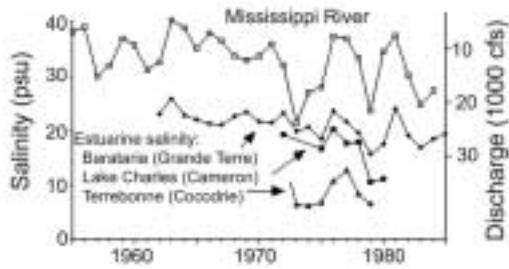


Figure 5. Time series plots of the combined annual mean flow of the Mississippi and Atchafalaya Rivers (open square) and plots of mean annual salinity from selected Louisiana Wildlife and Fisheries sampling stations within three Louisiana estuaries. River flow is in thousands of cubic feet per second (cfs) with a 15,000 cfs offset and is turned vertically to enhance visualization of the coherent patterns with estuarine salinity. It shows the effects of the river discharge variations on salinity in the estuarine bays. The relationship is dependent on freshwater entering through the open ocean passes during tidal excursions. Adapted from Wiseman et al., 1990.

of 30 centimeters by 2100.

Statistical models (Swenson in Ning et al., 2003) were developed describing the observed salinity at three stations (a “coastal station”, a “mid-estuary station”, and an “upper estuary station”) in the Barataria estuary, Louisiana, in terms of the major forcing functions (Mississippi River discharge, local precipitation, and coastal water levels).

The models were then used to predict the average salinity for each station using the data from 1990 through 2000 as an “index” period. The models reproduced the average annual salinity at each of the stations. The potential salinity changes that might occur with global climate changes in the forcing functions were estimated by changing the forcing functions during the index period to correspond to various climate change scenarios (increased or decreased precipitation and Mississippi River discharge). The resulting change in the annual pattern was then compared to the baseline condition. The results yield a potential change in salinity of ~3 psu (= 3 parts per thousand) for the salt marsh, and ~1 psu for the intermediate to brackish areas of the Barataria system.

A separate analysis of the relationship between freshwater inflow and average salinity supports these model predictions and inferences. A doubling of freshwater inflow decreases the time it takes to turnover the water volume of an estuary. The relationship between freshwater turnover (X) and salinity (Y) for 26 Gulf of Mexico (GOM) estuaries is shown in Figure 6. It suggests that halving the freshwater turnover time (a doubling of freshwater inflow) will result in a salinity decrease of only a few psu (on the average).

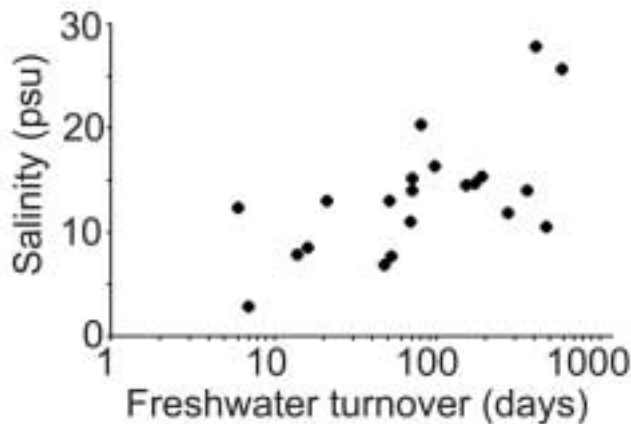


Figure 6. Freshwater inflow and salinity in Gulf of Mexico estuaries. Freshwater turnover is the estuarine volume divided by the freshwater inflow (from streams and precipitation) into the estuary. Increasing freshwater inflow will decrease the freshwater turnover time, leading to salinity reductions in the estuary. Adapted from Turner, 2001.

The likelihood of these changes occurring are difficult to assess because the present climate models give conflicting results on the expected changes in runoff (there is general agreement on precipitation changes). However, if changes of about 3 psu occur, then the potential impacts would most likely be limited to small scale vegetation community

changes at the boundaries of the major vegetation types. Larger salinity changes would be needed in order to see dramatic vegetation shifts in the coastal salt marshes.

The two climate models (Hadley and Canadian) used in this study give conflicting estimates of the potential changes in the hydrologic cycle (Boesch et. al., 2000). In general, there is low confidence in the predicted precipitation changes on a regional level (Adams and Gleick, 2000). This makes it difficult to assess the impacts around the Gulf of Mexico without detailed data from each estuarine system as was utilized in the Barataria assessment. However, some general statements regarding possible impacts can be made (Table 5). Stable systems such as Laguna Madre, Texas, or Atchafalaya Bay, Louisiana should not be affected by changes in the forcing functions that may result from global climate change, provided the changes are on the order of those predicted for the Barataria estuary (1 - 3 psu). These systems will only be effected by extremely large changes in the environmental forcing functions. The Types 2, 3, and 4 systems are the systems that would exhibit the greatest response to climate change due to their dynamic nature. In these systems, however, a negative change in one forcing function may be offset by a positive change in another forcing function. For example, in the Barataria System, a decrease in the local precipitation would lead to an increase in estuarine salinity, however, an increase in Mississippi River discharge occurring at the same time could offset this hypothetical salinity increase.

Table 5

Classification for Gulf of Mexico estuaries based on salinity variability as it relates to the character of the forcing functions. Listed, for each estuary type, is the stability level the forcing function and salinity variability characteristics, and example estuaries. This Table was adapted from data found in Orlando et. al., (1993).

Type	Description	Characteristics	Examples
1	Stable	<ol style="list-style-type: none"> 1. Salinity controlled by one factor. 2. Lack of dominant and continuous freshwater source 3. Salinity always at or near Gulf Salinities. 4. Very low to low salinity variability at all time scales. 	Tampa Bay, FL Corpus Christie Bay, TX Sarasota Bay, FL Laguna Madre, TX
2	Variable	<ol style="list-style-type: none"> 1. Salinity controlled by multiple factors. 2. Riverflow component important, tidal flow dominates 3. Medium to high variability at day-week time scales. 4. Low variability at day-week time scales. 5. Low to medium salinity variability at yearly time scales 	San Antonio Bay, TX Terrebonne/Timbalier, LA Aransas Bay, TX Barataria Bay, LA Apalachee Bay, FL
3	Variable	<ol style="list-style-type: none"> 1. Salinity controlled by multiple factors. 2. Riverflow and tidal flow are equal. 3. Medium variability at day-week time scales. 4. High variability at day-week time scales. 5. Medium salinity variability at yearly time scales. 	Suwanne River, FL Perdido Bay, FL Pensacola Bay, FL Apalachicola Bay, FL Mermantau River, LA
4	Variable	<ol style="list-style-type: none"> 1. Salinity controlled by multiple factors. 2. Tidal flow component important, river flow dominates 3. Low variability at day-week time scales 4. Medium variability at day-week time scales. 5. Low to Medium salinity variability at yearly time scales 	Sabine Lake, LA-TX Mobile Bay, LA Breton Sound, LA Galveston Bay, TX Calcasieu Lake, LA
5	Stable	<ol style="list-style-type: none"> 1. Salinity controlled by one factor. 2. Lack of dominant saltwater source. 3. Salinity values always quite low except for extreme 4. Low salinity variability at all times scales 	Atchafalaya Bay, LA Lakes Pontchartrain, LA Clealeleur Sound, LA Mississippi Sound, LA

3.2.2 Sustaining salt marshes amidst climate changes

Salt marshes, located at the seaward edge of the estuary must maintain their relative elevational position as sea level rises. If the marsh is flooded too often, then the soil the salt marsh plants grow on may become a hostile environment, and the plants will become physiologically stressed. If the soils do not accumulate enough organic and inorganic materials to compensate for both sea-level rise and for the lowering of the marsh soil (subsidence), then the marsh becomes open water. A healthy salt marsh accumulates just enough sediment over several years to survive the normal seasonal and annual fluctuations in water level. Inorganic material makes up less than 5% of the soil volume in salt marshes. The rest of the soil is water, which is held there by the organic material. Thus the relationship between vertical accretion and organic matter is stronger than between vertical accretion and inorganic material (Figure 7).

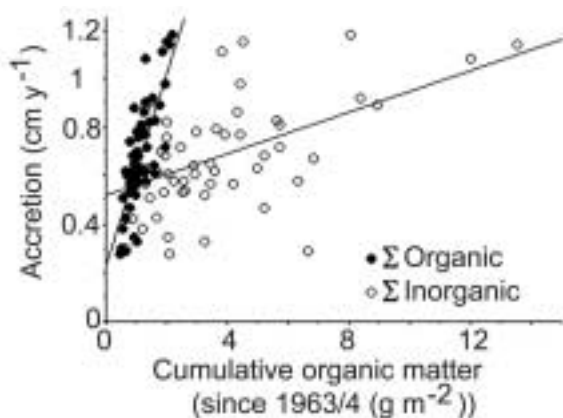


Figure 7. The relationship between the vertical accretion rate and the accumulated organic (left panel) and inorganic material (right panel). The data are for post 1963/4 accumulations. Adapted from data in Turner et al, 2001b.

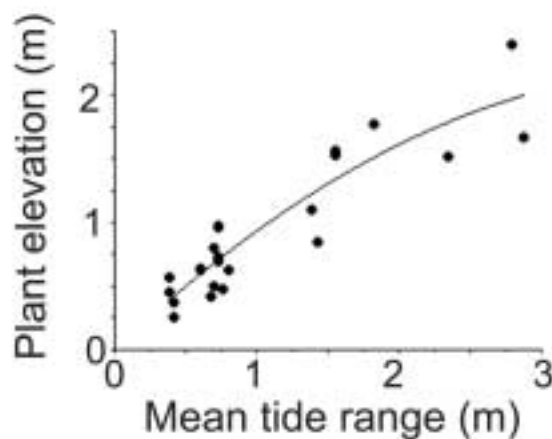


Figure 8. The relationship between the tidal range (X axis) and the elevation range within which the emergent salt marsh macrophyte *Spartina alterniflora* occupies. The tidal range at different locations within the Gulf of Mexico varies between 30 to 100 cm. Adapted from data in Mckee and Patrick, 1988.

GOM salt marshes occupy a rather narrow range (30 to 100 cm) within the intertidal zone, which is smaller than on the East Coast (Figure 8). A small change in a plant's elevation can make a big difference of whether or not its habitat is suitable, especially for plants living near the limits of their physiological tolerances. GOM salt marshes appear to be more susceptible to changes in subsidence and sea-level rise – a climate induced change. The marsh, in other words, is responsive to the seen (above ground) and unseen (below-ground) environmental factors affecting plant health.

What this means is that the health of the salt marsh plant, especially belowground, is probably the major factor determining whether or not salt marshes can survive in the face of rising sea-level and the sinking of the land upon which the plant is embedded. Most of the vertical adaptations that salt marsh plants must make are for subsidence, which is dominated by changes in the upper 2 meters (Turner, 1991). The changes from global sea-level rise (present and future) are usually less than half of these subsidence rate (Figure 9). However, not all plants occupy an 'average' position in the landscape. Plants on the lower end of the tidal range as shown in Figure 8 can be quite susceptible to even small changes in their flooding frequency.

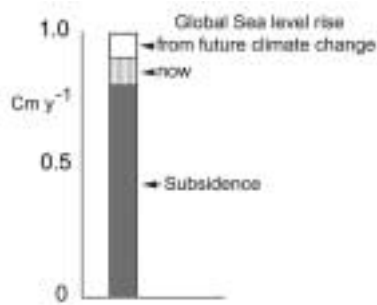


Figure 9. An example of the relative water level changes in a salt marsh due to subsidence from soil compaction and geological shifts and sinking (dark fill), present sea-level rise (gray fill) and projected additional future sea-level rise resulting from global climate change (unfilled). The total relative water level changes varies around the Gulf of Mexico, from zero to up to 1.3 cm y⁻¹.

There are other factors that interact with climate to influence the survivability of salt marshes. Some striking and novel results of other effects on coastal marshes arose from field experiments by Silliman and Zieman (2001) who demonstrated control of salt marsh macrophytic vegetation by snails. The common periwinkle, *Littorina irrorata*, has a profound effect on the health of the living salt marsh plant by grazing periphytic algae off the leaves and the leaves are damaged during the process. This effect increased with increasing nitrogen availability likely as the climate changes. Presumably, predation on periwinkles would affect the amount of damage done by the whole snail population. Predation could be influenced by commercial fishing pressure or competition by crabs, birds, and fish (all of which can be influenced by climate). In addition, nutrient availability, including too much nitrogen, can increase the decomposition of the below ground organic material (Morris and Bradley, 1999), perhaps leading to marsh collapse. Thus, the survivability of salt marshes is not dependent on one factor, but the interaction of many factors, including those affected by global climate changes. These complex relationships between habitat sustainability and ecosystem health can be cumulative and long-term in nature.

The upland side of the salt marshes is also sensitive to flooding, and other factors, reflecting the interactive nature of multiple influences. Sasser (1977) documented how four brackish and salt marsh plants were sensitive to both salinity and flooding (Figure 10). A plant might exist, or not, because of either too high a salinity, or an intolerance to the in situ flooding regime.

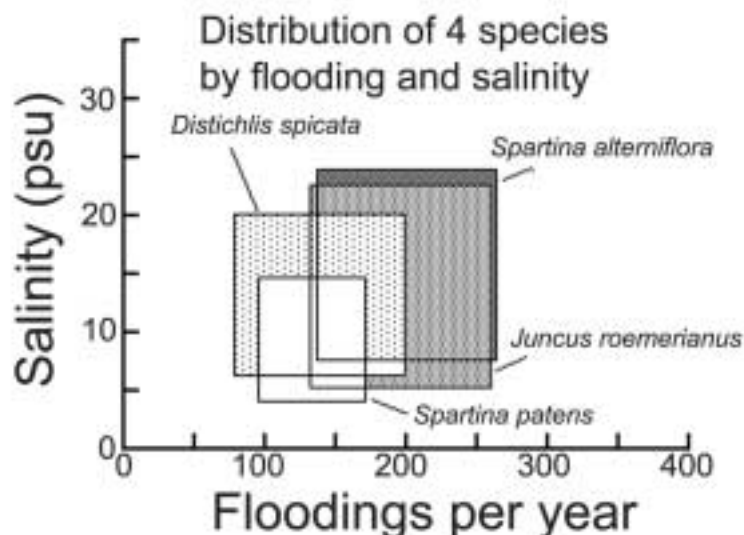


Figure 10. The distribution of four species of emergent estuarine plants described according to the flooding frequency and average salinity at each site. Note the close overlap for some species, and that a change in either salinity or flooding can change the competitive outcome for two species trying to occupy one location. Adapted from Sasser, 1977.

Models of the effects of doubling sea level rise on coastal wetland loss in Louisiana.

A computer model of the coastal Louisiana landscape was used to explore the effects of climate change on wetland loss rates (Reyes et al., in Ning et al., 2003). Two watersheds were examined (Figure 11). One landscape (Western Basin) had a prograding delta and the other a regressive delta (Barataria). The 6100 km² Barataria estuarine system is located between the natural levees of the Mississippi River and Bayou Lafourche. The Western Basin is bordered by Freshwater Bayou on the west and the Atchafalaya River on the east and occupies about 6765 km². The models attempted to link habitat interactions within these two basins across spatial and temporal scales using three coupled modules: a vertically integrated hydrodynamic module; a process-based biological module of above and below ground primary productivity; and a module for soil dynamics.

The models were run using pre-

sent sea-level rise rates and also a doubling of sea-level rise (0.18 and 0.40 cm y⁻¹, respectively) rates. The assumptions inherent to the model have varying levels of confidence, and there is no direct experimental mechanism to test their accuracy. Hindcasting model results against pre-1988 conditions is used, therefore, to test the model's accuracy. A minimum usefulness of the model is to teach scientists about the uncertainties in the model's assumptions, and, to predict the relative proportional changes in the two basins, and to estimate the relative changes in land loss with and without a doubling of sea-level rise. The predictions (Table 6) suggest that the two basins behave differently, which the authors attribute to the presence of the Atchafalaya River debouching into the Western Basin, in contrast to the Mississippi River delta's retreat in the other site (located offshore

of the Barataria Estuarine system). Interestingly, land loss in the Western Basin is predicted to be less

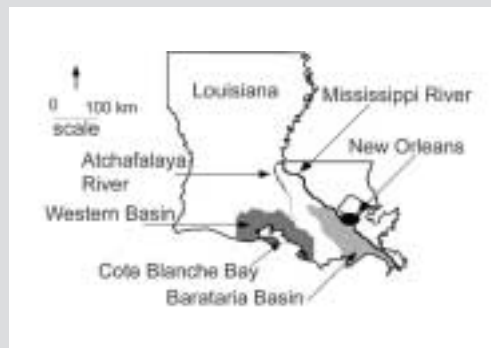


Figure 11. Location of the two basins included in the computer model of coastal land loss and sea-level rise changes.

than 5 % from 1988 to 2058 (70 years), and also that coastal land loss therein is unlikely to be dramatically affected by a doubling of sea-level rise. Land loss in the Barataria Basin was predicted to be 37% over the same interval, and to increase by an additional 9% if sea-level rise doubles (an additional 25% above the rates with a stable sea-level rise).

Table 6

Results from a computer model that explores the effects on coastal wetland loss using two assumptions: with and without a doubling of sea-level rise (SL) from 0.17 to 0.4 cm y⁻¹.

		Total Land (KM²)	Open Water (KM²)	Land loss 1988-2058	
From 1988 to 2058:					
Western Basin					
	1988	2157	6465		
projected without 2X SL rise in 2058		2057	6565	4.64%	Difference
projected with 2X SL rise by 2058		2056	6566	4.68%	+ 0.05%
Barataria Basin					
	1988	2971	2952		
projected without 2X SL rise in 2058		1866	4057	37.19%	Difference
projected with 2X SL rise by 2058		1604	4319	46.01%	+ 8.82%

3.2.3 Commercial Shrimp Harvests and Climate Change

There has been considerable research on how temperature and salinity govern estuarine communities, especially species of substantial economic interest. Estuaries are often called 'nursery grounds' because of the role they play in providing juveniles a relatively food-rich niche of reduced predation pressure. A slight reduction in mortality of young individuals can be quite important in determining the size of the adult population. Thus estuarine conditions have been used to predict future harvest success. Empirically-defined analyses of species composition, survival, or harvest over varying salinity and temperature ranges in Gulf of Mexico estuaries have been quite successful (e.g., Gunter 1950, Gunter et al. 1964, Copeland and Bechtel, 1974; Armstrong, 1982). Based on these analyses, it is quite clear that the effects of climate change will be significant. The temperature of slow moving or stagnant shallow waters is strongly influenced by air temperatures, which are postulated to increase by 3-5°F as atmospheric carbon dioxide doubles. Estuaries with limited mixing will be more stratified as temperature rises (also reducing bottom water oxygen concentration), especially during summer.

The commercial shrimp fisheries of the northern Gulf of Mexico are based on the capture of brown and white shrimp, and much smaller quantities of pink and red shrimp. The general life cycle of brown and white shrimp includes an offshore spawning stock. One female may release one million eggs, which suggests a very high mortality rate. The free-floating larvae make their way into coastal estuaries and may have some ability to move vertically to maximize the different current flows within a stratified water column. Once in the estuary they live at the wetland edge and within the wetland (depending on water levels), where they grow large enough over several months to eventually migrate offshore as post-larvae or juveniles and be caught, eaten and/or reproduce. The entire cycle from birth to harvest is ordinarily 12 months.

The large annual variations in shrimp harvest from year-to-year are associated with changes in estuarine conditions when the juveniles are in the estuary. Variation in estuarine salinity and temperature at the time of estuarine use by the shrimp are the best-documented climatic influences for many places throughout the world (Table 7). The frequency and intensity of passages of meteorological fronts, may also be important. Copeland and Bechtel (1974) analyzed the salinity and temperature preferences of several penaeid (shrimp) species in estuaries of the northern Gulf of Mexico. It is clear that there is an interactive *optimal* preference by shrimp for temperature and salinity, rather than a linear relationship dominated by one factor. The result is that several state fish and game agencies predict shrimp fisheries harvest on the basis of spring salinity and temperature, or from surrogate measures of salinity, such as riverflow. For example, there is an annual variation in the Gulf of Mexico shrimp catch that is negatively related to annual variations in riverflow (more flow, less shrimp and vice versa) (Figure 12), implying a riverine control on estuarine salinity. However, yields may also be influenced by non-environmental factors. For example, the higher yield in recent years regardless of flow may be the result of the more greater fishing effort, gear changes, improved fishing knowledge, increased wetland 'edge' (resulting from wetland fragmentation), economic incentives, or, improved reporting of the actual catch. Normally, predictive efforts are successful because larval recruitment from the spawning sites offshore into estuaries is so high that postlarval growth and survival in the estuary are probably the most important factors affecting the harvestable adult population size. Estuarine salinity and temperature changes affect the variations in annual postlarval survival, perhaps for physiological reasons, or for the indirect influences on food supply or predators. Nevertheless, it is clear that variations in climate, and future climate change, will affect fisheries yields.

Although postlarval growth and survival in the estuary are the most important factors affecting the harvestable adult population size from year-to-year, the *long-term* yields are directly related to both the quantity and quality of intertidal habitat. This conclusion is supported by the strong linear relationship between shrimp and the area of estuarine vegetation, from Louisiana to Florida (Figure 12). There is no obvious relationship between harvest and open estuarine water surface area, except for a possible inverse relationship. In addition, the species of shrimp caught are directly related to the kinds of intertidal coastal vegetation in a specific location. The implication of this conclusion is that habitat changes in the estuary (e.g., from climate change as well as other factors) will affect shrimp yields.

Model predictions for climate change in the northern Gulf of Mexico suggest that both temperature and riverflow will increase. The present relationship between riverflow and commercial yields is negative (Figure 13). Therefore, the short term effect of higher discharge rates will be a decrease in overall yields. There may be some adjustments as the estuarine watershed vegetation changes with lower salinities. The longer term prospects are, however, even worse because dependency of the shrimp on the intertidal vegetation. It might seem that the fresher part of the estuary will move inland. However, the elevation gradient increases in many parts of the Gulf of Mexico, which will cause a squeezing of space for intertidal habitat. The result of these interacting forces will be lower shrimp yields for the same amount of fishing effort. The implication of the relationship between riverflow and shrimp yields shown in Figure 12 is that a 30% rise in river discharge could result in a 15 to 20 % reduction in shrimp yields in the northern Gulf of Mexico.

Table 7

**Examples of the effects of climate on coastal penaeid shrimp stocks.
Adapted from Turner, 1989.**

Location	Species	Effect on yields
North Carolina	<i>P. duorarum</i>	temperature (-)
Louisiana	<i>P. setiferus</i>	salinity (-)
		temperature (+)
	<i>P. aztecus</i>	salinity (+)
		temperature (+)
Northern Gulf of Mexico (USA)	<i>P. setiferus</i>	salinity (-)
		temperature (+)
	<i>P. aztecus</i>	salinity (+)
		temperature (+)
Florida	<i>P. duorarum</i>	water level (+)
Laguna Madre, Texas (periodically hypersaline)	<i>P. fluviatilis</i>	rainfall (+)
	<i>P. aztecus</i>	
Australia	<i>P. merguensis</i>	rainfall (+)
Indonesia	<i>P. merguensis</i>	riverflow (+)
	<i>P. monodon</i>	
Senegal	<i>P. duorarum</i>	salinity (+)

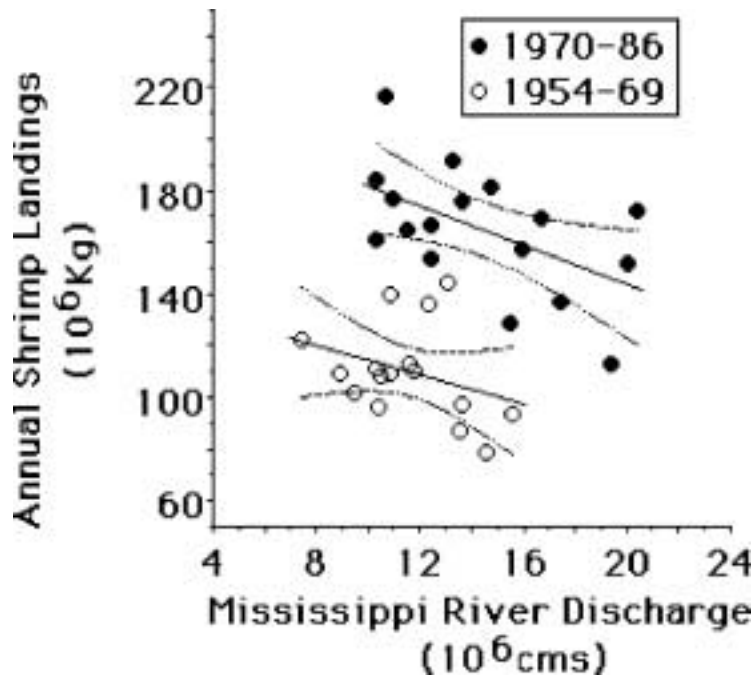


Figure 12. The relationship between the annual yields of shrimp in the Gulf of Mexico and discharge of the Mississippi river. The 95% confidence limit for the y value of each linear regression is shown. Temperature is also an important covariable. (Adapted from Turner, 1992).

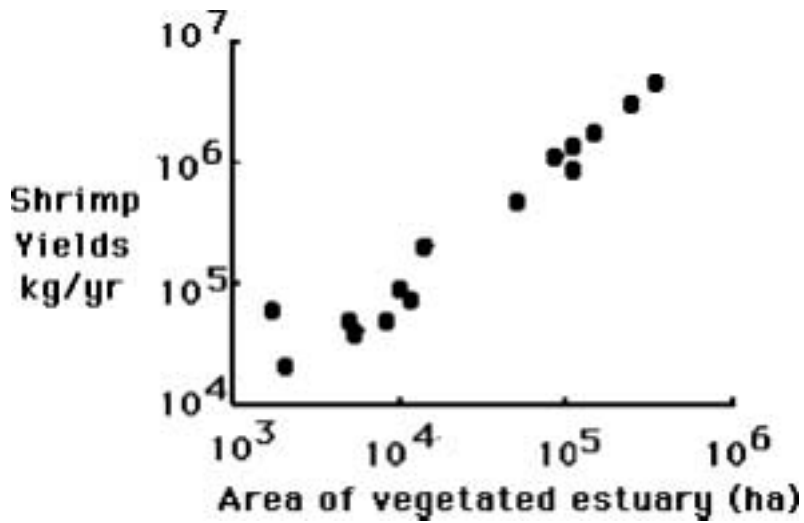


Figure 13. The relationship between intertidal vegetation and penaeid shrimp yields from the estuaries of the northern Gulf of Mexico (adapted from Turner, 1977).

3.2.4 Hypoxia and climate change

Hypoxia occurs when the oxygen content of bottom waters fall below 2 mg l^{-1} . This cut-off point is the empirically-defined limit below which shrimp and fish are usually absent. Anoxia occurs where there is no oxygen in bottom layers.

What Causes Hypoxia ?

Two principal factors lead to the development and maintenance of hypoxia in coastal waters: (1) a physically-stratified water column, and, (2) decomposition of organic matter in the bottom layer. The water column must be stratified so that the bottom layer is isolated from the surface layer with the result that normal diffusion of oxygen from surface to bottom layers is reduced. Fresher waters derived from rivers and seasonally-warmed surface waters are less dense and reside above the saltier, cooler and more dense water masses near the bottom. This isolation reduces the reaeration of oxygen from atmosphere to surface layer to bottom waters. The stratified system may be interrupted by wind-mixing events, notably tropical storms and winter cold fronts.

The decomposition of organic matter in the bottom layer consumes oxygen, but stratification prevents an equilibrium concentration that is sufficient to maintain oxygen concentrations sufficient to support many life forms, including fish and shrimp. The source of this organic matter is mostly from phytoplankton growth in surface water. Phytoplankton not incorporated into the food web and fecal material generated via the food web sink into bottom waters where they are decomposed by aerobic bacteria, and oxygen is depleted. The concentrations and total loads of nitrogen, phosphorus and silica influence the quantity and quality of phytoplankton community and, ultimately, the flux of the phytoplankton-derived organic matter.

The relative influence of the physical features of the system and the progression of biological processes varies spatially and over an annual cycle. In the northern Gulf of Mexico the physical and biological processes are complexly inter-related and directly linked with the dynamics of rivers, atmospheric sources, and groundwater.

Where is Hypoxia/Anoxia in the Gulf of Mexico ?

Decreased concentration of dissolved oxygen (=hypoxia) occurs in many parts of the world's aquatic environments. Hypoxic and anoxic (no oxygen) waters have existed throughout geologic time and presently occur in many of the ocean's deeper environs, but their occurrence in shallow coastal and estuarine areas appears to be increasing, most likely accelerated by human activities (Diaz and Rosenberg, 1995).

The second largest zone of coastal hypoxia (= oxygen depleted waters) in the world is found on the northern Gulf of Mexico continental shelf adjacent to the outflows of the Mississippi and Atchafalaya rivers (Figure 14). The mid-summer bottom areal extent of hypoxic waters ($< 2 \text{ mg l}^{-1} \text{ O}_2$, or ppm) in 1985 - 1992 averaged 8,000 to 9,000 km^2 but increased to 16,000 to 20,000 km^2 in 1993 - 1999 (Rabalais and Turner, 2000). The estimated extent was 12,500 km^2 in mid-summer of 1998, and 4,400 km^2 in 2000 and reached a record size of 20,700 km^2 in mid-summer 2001 (Rabalais, 2001). Hypoxia is not found as just a thin lens overlying bottom sediments, but occurs well up into the water column depending on the location of the pycnocline(s). Depending on the depth of the water, hypoxia may encompass from 10% to over 80% of the total water column, but is normally

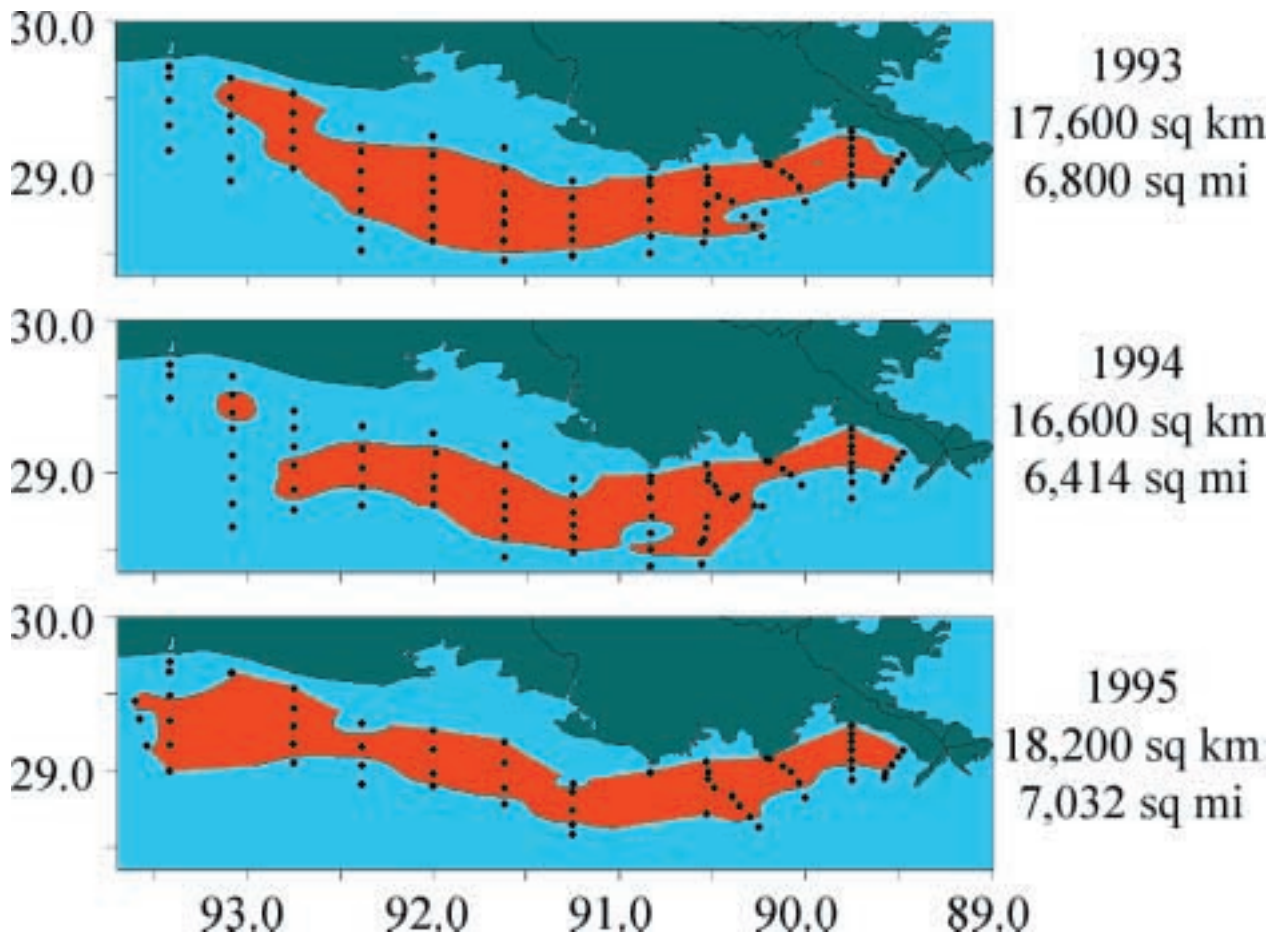


Figure 14. Hypoxia in bottom waters during the summer west of the Mississippi River delta. Graphics provided by N. N. Rabalais and colleagues and are described in Rabalais et al., 1999.

only 20 to 50% of the water column. At the high end of this range, hypoxic waters may reach to within 2 m of the surface in a 10-m water column, or to within 6 m of the surface in a 20-m water column.

Hypoxia or anoxia is also found in most of the Gulf of Mexico estuaries (Figure 15). When hypoxia occurs in Mobile Bay or nearby coastal waters, fish can be trapped along the shore where they are easily capture (and sometimes moribund). These events are called “Jubilees” if the fish are moribund when captured, but not dying. Jubilees also happen in Louisiana along barrier island beaches.

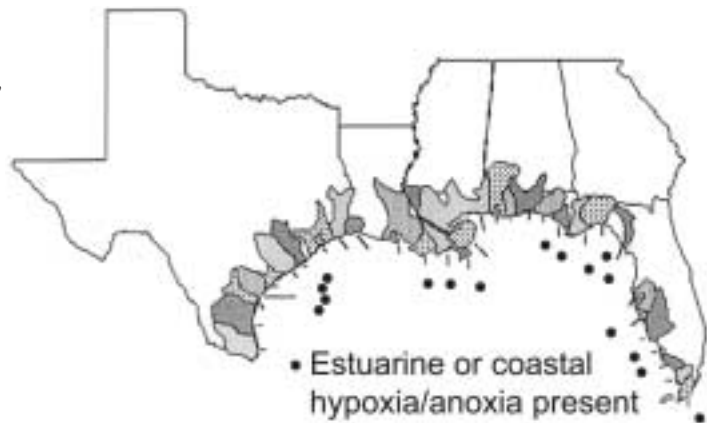


Figure 15. Estuaries in the Gulf of Mexico that have a record of periodic hypoxia or anoxia.

Some Biological Effects of Hypoxia

The hypoxic zone off Louisiana is often referred to as the “Dead Zone” in the popular press and literature. The term “dead zone” refers to the failure to capture fish, shrimp, and crabs in bottom-dragging trawls when the oxygen concentration falls below 2 mg l^{-1} in the water covering the seabed (Leming and Stuntz, 1984; Renaud, 1986). The numbers of stressed or dying benthic (bottom) organisms within the sediments increase substantially when the oxygen levels remain low for prolonged periods (Rabalais et al., 2001). Higher up in the water column and in the surface mixed layer, however, there is sufficient oxygen to support sizable populations of swimming fish and crabs. Also, there are anaerobic or hypoxia-adapted organisms that survive in sediments overlain by hypoxic or anoxic waters, so that the term “dead zone” is not entirely applicable to the whole of the area designated “hypoxic” (several chapters in Rabalais and Turner, 2001). Still, the area is large, approaching the size of the state of Massachusetts in 2001, and garners public attention primarily because of the loss of catchable fish and shrimp.

Mass mortalities are likely if infauna are trapped against the shore by a large anoxic water mass. Heavy mortalities occur in the bottom dwelling organisms and species diversity is drastically reduced when ambient oxygen concentrations decrease below 0.5 mg l^{-1} (Gaston, 1985; Boesch and Rabalais, 1999; Rabalais et al., 1993, 2001). There is some recovery of the benthic community after hypoxic events are over. However, the overall structure of benthic community is shifted in species composition and age structure, to a smaller-sized, lower biomass, polychaete (worm) dominated fauna. An increase in areal extent and severity of hypoxia will decrease recovery rates and also reduce food resources (infauna) for recolonizing demersal groups, such as the commercially important penaeid shrimps. Further, alterations in benthic community structure will have implications for sedimentary processes, benthic pelagic coupling, and energy flow. Major alterations in benthic communities due to hypoxia stress, especially a reduction in diversity and biomass, will certainly alter the productivity base that leads to fishery stocks. Further, fishers have to travel farther to catch the migrating fisheries stocks that avoid hypoxic areas, thus reducing net economic returns.

Climate Change and Hypoxia

Freshwater discharge and seasonal atmospheric warming control the strength of stratification necessary for the development and maintenance of hypoxia. The combined long-term average annual discharge for the Mississippi and Atchafalaya Rivers to the Gulf of Mexico is $19,920 \text{ m}^3 \text{ s}^{-1}$ (1930-1997 period) (Bratkovich et al., 1994, Goolsby et al., 1999). The long-term peak flow occurs in March, April, and May, and the long-term low flow is in summer and early fall. Although flow is reduced in summer, large-scale circulation patterns facilitate the retention of the fresh water on the shelf (Rabalais et al., 1999). There is significant interannual variability in discharge, but the long-term average discharge for the lower Mississippi River is remarkably stable near $14,000 \text{ m}^3 \text{ s}^{-1}$ (Turner and Rabalais, 1991; Bratkovich et al., 1994). Less obvious is a statistically significant and increasing trend in the Mississippi River discharge for 1900-1992 as measured at Tarbert Landing (Bratkovich et al., 1994). It appears to be due to a tendency for increasing discharge in September through December. This period, however, is much less important in the coastal ocean than spring and summer in the timing of important biological processes that lead to the development of hypoxia or the physical processes important in its maintenance. If a longer period of annual discharge were considered, e.g., for the early 1800s to present, the trends since the

1950s are obvious but are concealed within high interannual variability and no long-term change over a century and a half (Rabalais et al., 1999).

The projected global climate changes in the Gulf of Mexico includes higher temperatures, altered seasonal variations in river discharge and precipitation, and increased precipitation and (probably) Mississippi River discharge. Both increased temperature and freshwater discharge will affect the size and severity of hypoxic water masses in the Gulf of Mexico. Climate changes in the Gulf of Mexico will affect both of these factors, and often in a negative way. An example of the interrelationship between temperature (which is directly related to organic decomposition rates), stratification and hypoxia is shown in Figure 16. Hypoxia in Charlotte Harbor is most likely to occur at higher temperatures and during periods of water column stratification. A lack of wind mixing of the water column may also encourage the likelihood of hypoxic events. Jubilees in Mobile Bay, for example, occur during the summer when wind speed is relatively low (Figure 17).

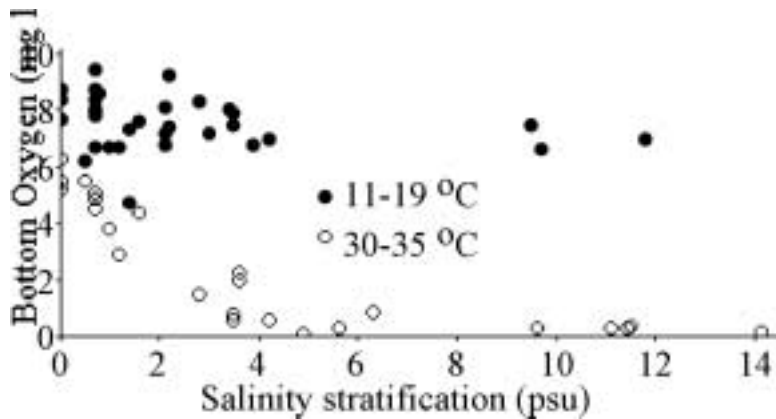


Figure 16. The relationship between salinity stratification between surface and bottom water (x axis) and bottom water (y axis, mg l^{-1}) oxygen concentration in upper Charlotte Harbor, Florida. Data are for June-October from sampling by the South Florida Water Management District. Two portions of the data are included: where temperature in the surface water is 30°C or higher (open circles) and between 11 and 19°C (filled circles). From Turner et al., 2001.

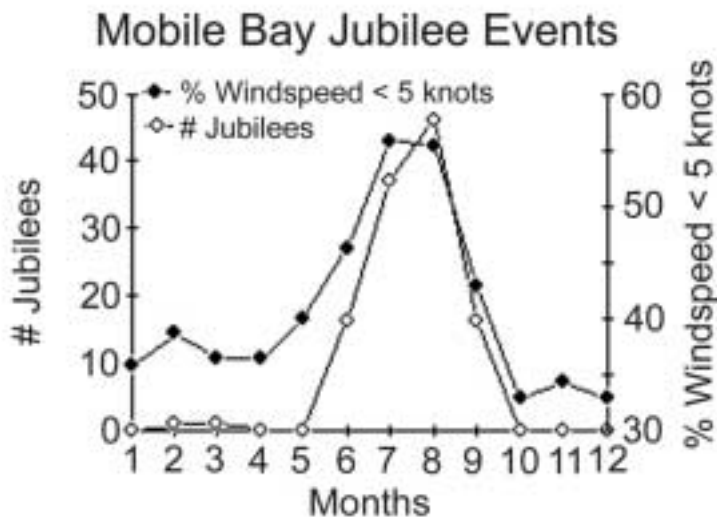


Figure 17. The percent monthly occurrence of low winds (< 5 knot wind speeds, 1974 - 1984) and the historical record of the total number of 'jubilees' in Mobile Bay by month from 1946 - 1971. Adapted from Turner et al., 1987.

Models of Climate Change Effects on Hypoxia

Because model projections for the Mississippi River runoff are highly variable, the assessments of future climate change scenarios for the northern Gulf of Mexico are complicated. The Canadian and the Hadley models projected a 30% decrease and a 40% increase, in run off respectively, by the year 2099. Justić (2003 in Ning et al.) developed a eutrophication model to describe changes in surface and bottom oxygen concentrations within the core of the Gulf of Mexico hypoxic zone. A plot of the model results and the actual data are shown in Figure 18. A sensitivity analysis revealed that the model is highly sensitive to external forcing, yet sufficiently robust to withstand order of magnitude changes in the nitrate flux of the Mississippi River.

Model simulations suggest that altered freshwater and nutrient fluxes would have important implications for water column stability, net productivity and global oxygen cycling in the northern Gulf of Mexico. A doubling of atmospheric carbon dioxide would lead to higher temperatures, increased runoff and longer, more severe and larger hypoxic zones in the northern Gulf of Mexico (Figure 19). Nominal model simulation for the period 1954-2000, for example, predicted 19 years with moderate hypoxia ($< 2 \text{ mg O}_2 \text{ l}^{-1}$) and 16 years with severe hypoxia ($< 1 \text{ mg O}_2 \text{ l}^{-1}$). A 30% decrease in the Mississippi River discharge for the same period would have significantly reduced the number of years with moderate and severe hypoxia to 8 and 4, respectively. For a scenario with 4°C increase in the average annual temperature and a 20% increase in the average Mississippi River discharge, the model predicts 31 year with moderate and 26 years with severe hypoxia. Importantly, model simulations suggest that pronounced hypoxia would not develop if the nitrate concentrations would had remained unchanged with respect to the period 1954 - 1967 (0.61 mg N l^{-1}). Thus, depending on future climate change scenarios and nutrient control strategies, hypoxia in the northern Gulf of Mexico may become more or less severe.

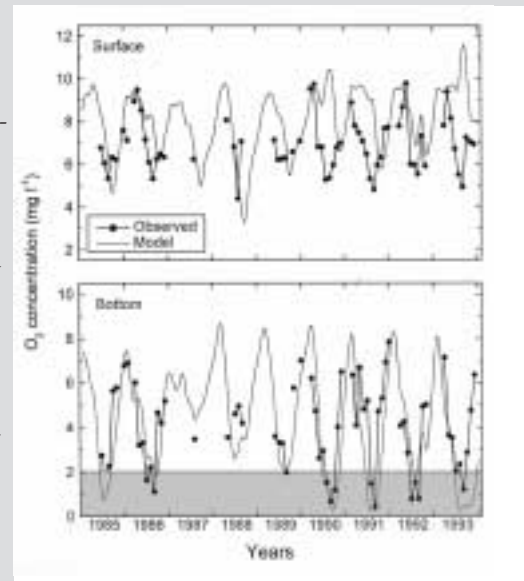


Figure 18. Observed and predicted monthly averages of surface (0-10 m) and bottom (10-20 m) oxygen concentrations at station C6 for the period June 1985-November 1993. From Justić in Ning et al., 2003.

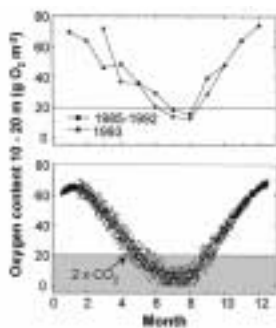


Figure 19. Seasonal changes in the integrated subpycnoclinical oxygen content (10-20m) at station C6 in the core of the hypoxic zone. Observed monthly averages for 1985 - 1992 and 1993 are compared to a Monte-Carlo simulation for a $2\times\text{CO}_2$ climate. The $2\times\text{CO}_2$ probability plot is comprised of 2880 points. From Justić et al., 1996.

Model simulations indicated that bottom water hypoxia in the northern Gulf of Mexico has intensified in recent historical time, as a probable consequence of increased net productivity and an increase in the vertical flux of organic carbon. Apparently, the long-term increase in riverine nutrient fluxes has been the primary factor controlling this historical decline in oxygen concentrations. Nevertheless, the influence of climatic factors on nitrate flux has been significant and could further increase as a result of global climate change (Figure 20).

In contrast to a relatively high degree of confidence associated with the projected temperature increases, the effects of global climate change on the hydrological cycle are less certain, particularly on regional scales. The annual Mississippi River runoff, for example, was projected to decrease by 30% for the Canadian model, but increase by 40% for the Hadley model by the year 2099. Model simulations further suggest that altered freshwater and nutrient fluxes would have important implications for water column stability, net productivity and global oxygen cycling in the northern Gulf of Mexico. Direct and indirect fisheries losses would likely be exacerbated if hypoxia expands in space or time as a result of global climate change.

The results of this model suggest that a large-scale reduction (~30%) in nitrogen concentration of the Mississippi River would eventually diminish the severity of hypoxia in the northern Gulf of Mexico. Nevertheless, the areal extent and the severity of hypoxia are very sensitive to climate-induced changes in freshwater and nutrient fluxes. If, for example, the Mississippi River discharge increases by 20%, as predicted in some climate change model scenarios, then a reduction in nitrate flux in excess of 20% would be required only to prevent the eutrophication from worsening. Consequently, nutrient control efforts for the Mississippi River watershed that are based solely on achieving a specific reduction in the non-point source nutrient loading, may have limited success in controlling the eutrophication and hypoxia in the northern Gulf of Mexico.

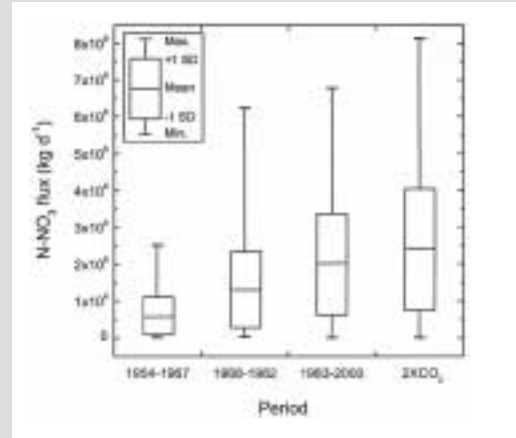


Figure 20. Box-plots showing nitrate flux (N-NO₃ flux) statistics for 1954-1967, 1968-1982, and 1983-2000, as well as projections for a 2xCO₂ climate based on a 20% increase in the Mississippi River runoff (Miller and Russell 1992). From Justić in Ning et al., 2003.

3.3 Response, Coping/Adaptation Options, and Information and Research Needs

The preceding discussion illustrated several ways in which likely climate changes could affect coastal ecosystems. The physical structure of coastal systems may be changed through alterations in salinity, temperature, and sea-level rise as well by reactions to those in the form of habitat changes, for example, the replacement of emergent vegetation with open water. Any or all of these changes could affect wetland and coastal fisheries through direct or indirect reduction of food supply means. Also, coping options in place to deal with present environmental stresses could be in jeopardy. For example, upstream nutrient reduction strategies meant to reduce the severity and frequency of hypoxic events could be compromised by increased riverflow as a result of variations in precipitation. Therefore, developing any set of response; coping, or adaptation options needs to include present stress and strategies as well as future complications from human activities (Figure 21).

However, it is also prudent to consider that some stressor impacts can be rolled back, but only reduced. Sea-level rise, for example, will probably continue, but at a lower rate than expected as a result of the anticipated from global climate changes. Under these circumstances, prevention is not enough, and future adjustments should be planned and anticipated. That type of planning and adjustment requires a substantial improvement in our knowledge and experience. The highlighted issues brought forth in this review suggest that this improvement should include long-term and comprehensive (integrated) programs that promote understanding of:

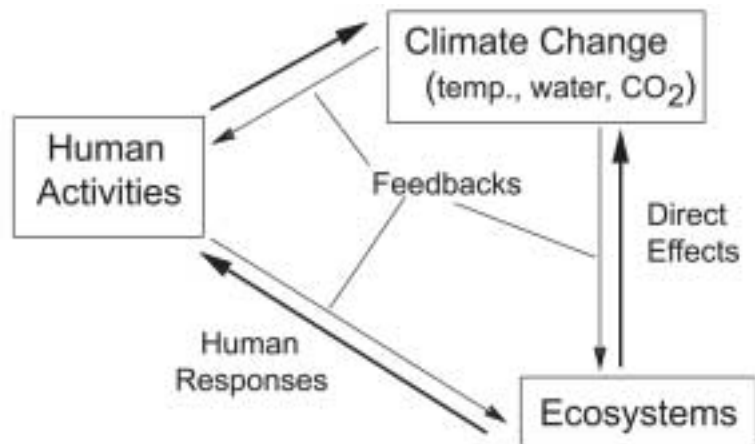


Figure 21. The effects and feedbacks in the interacting systems of climate, ecosystems and human societies. Adapted from Mulholland et al., 1997.

- (1) Wetland soil sustainability within the context of the entire organic and inorganic framework, and how the marsh ecosystem is affected by multi-year exposure to varying nutrients, altered food webs, and freshwater inflow management meant to provide single-problem solutions - e.g., oyster harvests or salinity management.
- (2) The interactions between the social/political structure and function and the ecosystem attributes. The involvement of educators, social scientists, and natural scientists is required to find successfully-implement solutions to these complex problems.
- (3) Scenario testing approaches to strategically analyze the anticipated problems before their impact overwhelms abilities to react. Some approaches might involve computer modeling, others experimental field testing of contrasting methods, and still others comparative analyses of social and natural systems outside of the immediate region.
- (4) Control and management options for land use, harvest management, and water quality,

with attention to the evaluation of unusual events (and subsequent management pressures) and competing resources claims.

- (5) Mechanisms and models of how build a better "tool kit" which has alternative options and support to try things, with the knowledge that, for some resources, we will only get one chance to fix the problem before it is unmanageable. We must be open to all kinds of solutions.

• REFERENCES •

- Adams, D. B., and P. H. Gleick 2000. *Potential Impacts of Climate Change and Variability on the Water Resources of the United States. Draft Report of the Water Sector of the National Assessment of the Potential Consequences of Climate Variability and Change. U.S.G.C.R.P./ National Assessment Coordination Office, 400 Virginia Avenue, SW Suite 750. Washington, DC 20024. 108 pp. Available on the web at <http://www.cop.noaa.gov>.*
- Armstrong, N. E. 1982. *Responses of Texas estuaries to freshwater inflows. pp. 103-120, In: Estuarine Comparisons. Academic Press, Inc. New York.*
- Belt, C. B. Jr. 1975. *The 1973 flood and man's constriction of the Mississippi River. Science 189: 681-684.*
- Boesch, D. F., and N. N. Rabalais 1991. *Effects of hypoxia on continental shelf benthos: comparison between the New York Bight and the northern Gulf of Mexico, p. 27-34. In R. V. Tyson, and T. H. Pearson [eds.], Modern and ancient continental shelf hypoxia, Geological Society Special Publication No 58, London.*
- Boesch, D. F., J. C. Field, and D. Scavia (Eds.) 2000. *The Potential Consequences of Climate Variability and Change on Coastal Areas and Marine Resources: Report of the Coastal Areas and Marine Resources Sector Team, U. S. National Assessment of the Potential Consequences of Climate Variability and Change, U. S. Global Research Program, NOAA Coastal Ocean Program Decision Analysis Series #21. NOAA Coastal Ocean Program, Silver Spring, MD. 163 pp. Available on the web at <http://www.nacc.usgcrp.gov/sectors/water/draft-report/full-report.html>.*
- Bratkovich, A., S. P. Dinnel, and D. A. Goolsby 1994. *Variability and prediction of freshwater and nitrate fluxes for the Louisiana-Texas shelf: Mississippi and Atchafalaya River source functions. Estuaries 17: 766-778.*
- Chabreck, R. 1972. *Vegetation, water and soil characteristics of the Louisiana coastal region. La. Agricultural Experiment Station., AEA Information Series 25. Baton Rouge, LA. 72 pp.*
- Copeland, B. J., and T. J. Bechtel 1974. *Some environmental limits of six gulf-coast estuarine organisms. Contr. Mar. Sci. 18: 169-204.*
- Diaz R. J., and R. Rosenberg 1995. *Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology: an Annual Review 33: 245-303.*
- Gaston, G. R. 1985. *Effects of hypoxia on macrobenthos of the inner shelf off Cameron, Louisiana. Estuar. Coast. Shelf Sci. 20: 603-613.*
- Goolsby, D. A., W. A. Battaglin, G. B. Lawrence, R. S. Artz, B. T. Aulenbach, R. P. Hooper, D. R. Keeney, and G. J. Stensland 1999. *Flux and Sources of Nutrients in the Mississippi-Atchafalaya River Basin: Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 15. NOAA Coastal Ocean Office, Silver Spring, MD.*
- Gunter, G. 1950. *Seasonal population changes and distributions as related to salinity, of certain invertebrates of the Texas coast, including the commercial shrimp. Publ. Inst. mar. Sci. 1: 7-51.*
- Gunter, G., J. Y. Christmas, and R. Killebrew 1964. *Some relations of estuaries to population distributions of local estuarine organisms, with special reference to penaeid shrimp. Ecology 45: 181-185.*
- Justić, D., N. N. Rabalais, R. E. Turner, and W. J. Wiseman, Jr. 1993. *Seasonal coupling between riverborne nutrients, net productivity and hypoxia. Marine Pollution Bulletin 26: 184-189.*
- Justić, D., N. N. Rabalais, and R. E. Turner 1996. *Effects of climate change on hypoxia in coastal waters: A doubled CO2 scenario for the northern Gulf of Mexico. Limnol. Oceanogr. 41: 992-1003.*
- Justić, D., N. N. Rabalais, and R. E. Turner 1997. *Impacts of climate change on net productivity of coastal waters:*

- implications for carbon budgets and hypoxia. *Climate Res.* 8: 225-237.
- Keddy, P. A. 2000. *Wetland Ecology: Principles and Conservation*. Cambridge Studies in Ecology, Cambridge University Press, Cambridge, England.
- Knox, J. C. 1993. Large increases in flood magnitude in response to modest changes in climate. *Nature* 361: 430-432.
- Leming T. D., and W. E. Stuntz 1984. Zones of coastal hypoxia revealed by satellite scanning have implications for strategic fishing. *Nature* 310: 136-138.
- Mckee, K. L., and W. H. Patrick, Jr. 1988. The relationship of smooth cordgrass (*Spartina alterniflora*) to tidal datums: A review. *Estuaries* 11: 143-151.
- Miller, J. R., and G. L. Russell 1992. The impact of global warming on river runoff. *J. Geophys. Res.* 97: 2757-2764.
- Morris, J. M., and P. Bradley 1999. Effects of nutrient loading on the carbon balance of coastal wetland environments. *Limnol. Oceanogr.* 44: 699-702.
- Mulholland, P. J., G. R. Best, C. C. Coutant, G. M. Hornberger, J. L. Meyer, P. J. Robinson, J. R. Stenberg, R. E. Turner, F. Vera-Herrera, and R. G. Wetzel. 1997. Effects of climate change on freshwater ecosystems of the south-eastern United States and Gulf Coast of Mexico. *Hydrobiologia* 11: 949-970.
- NOAA. 1991. *Coastal wetlands of the United States: An accounting of a national resource base*. National Ocean and Atmospheric Administration. Report 91-3. 59 pp.
- Ning, Z. H., and K. K. Abdollahi 1999. *Global Climate Change and Its Consequences on the Gulf Coast Region of the United States*. GCRCC, U.S. Federal Building, Baton Rouge, LA 70821-4292, Franklin Press Inc., Baton Rouge, LA 70802.
- Ning, Z. H., R. E. Turner, D. Doyle, and K.K. Abdollahi 2003. *Integrated Assessment of the Potential Consequences of Climate Change for the Gulf Coast Region*. GCRCC and LSU Press, Baton Rouge, LA.
- Orlando, S. P. Jr., L. P. Rozas, G. H. Ward, and C. J. Klein. 1993. *Salinity characteristics of Gulf of Mexico estuaries*. Silver Spring, MD: National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment. 209 pp.
- Pavela, J. S., J. L. Ross, and M. E. Chittenden, M. E., Jr. 1983. Sharp reduction in abundance of fishes and benthic macroinvertebrates in the Gulf of Mexico off Texas associated with hypoxia. *Northeast Gulf Science* 6: 167-173.
- Rabalais, N. N., R. E. Turner, W. J. Wiseman, Jr., and D. F. Boesch 1991. A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988. *J. Geol. Soc. (London) Sp. Publ.* 58: 35-47.
- Rabalais, N. N., L. E. Smith, E. B. Overton, and A. L. Zoeller 1993. Influence of hypoxia on the interpretation of effects of petroleum production activities. OCS Study/MMS 93-0022. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.
- Rabalais, N. N., W. J. Wiseman, Jr., and R. E. Turner 1994. Comparison of continuous records of near-bottom dissolved oxygen from the hypoxia zone along the Louisiana coast. *Estuaries* 17: 850-861.
- Rabalais, N. N., R. E. Turner, D. Justić, Q. Dortch, W. J. Wiseman, Jr., and B. K. Sen Gupta 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* 19: 386 - 407.
- Rabalais, N. N., R. E. Turner, W. W. Wiseman, Jr., and Q. Dortch 1998. Consequences of the 1993 Mississippi River flood in the Gulf of Mexico. *Regulated Rivers: Research & Management* 14: 161-177.
- Rabalais, N. N., R. E. Turner, D. Justić, Q. Dortch, and W. J. Wiseman, Jr. 1999. *Characterization of Hypoxia: Topic 1 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico*. NOAA Coastal Ocean Program Decision Analysis Series No. 15. NOAA Coastal Ocean Office, Silver Spring, MD.
- Rabalais, N. N., and R. E. Turner (eds.). 2001. *Coastal Hypoxia: Consequences for Living Resources and Ecosystems*. Coastal and Estuarine Studies Series Vol. 58, American Geophysical Union. Washington, D.C. 463 pp.
- Rabalais, N. N., D. E. Harper, and R. E., Turner 2001. Responses of nekton and demersal and benthic fauna to decreasing oxygen concentrations, p. 115-129. In. N. N. Rabalais and R. E. Turner (eds.), *Coastal Hypoxia:*

Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

- Renaud, M. L. 1986. Hypoxia in Louisiana coastal waters during 1983: implications for fisheries. *Fishery Bull.* 84: 19-26.
- Sasser, C. S. 1977. *Distribution of vegetation in Louisiana coastal marshes as response to tidal flooding. M.S. Thesis, Louisiana State University, Baton Rouge, LA. 40 pp.*
- Silliman, B. R., and J. C. Zieman 2001. Top-down control of *Spartina alterniflora* production by periwinkle grazing in a Virginia salt marsh. *Ecology* 82: 2830-2845.
- Turner, R. E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. *Trans. Am. Fish. Soc.* 106: 411-416.
- Turner, R. E. 1982. Protein yields from wetlands. Pp. 405-415, In: B. Gopal, R. E. Turner, R. G. Wetzel, and D. F. Whigham (eds.). *Wetlands: Ecology and Management. Intl. Scientific Publ. Jaipur, India. 514 pp.*
- Turner, R. E. 1991. Tide gage records, water level rise and subsidence in the northern Gulf of Mexico. *Estuaries* 14: 139-147.
- Turner, R. E. 1992. Coastal Wetlands and Penaeid Shrimp Habitat. pp. 97-104, In: R. H. Stroud (ed.) *Stemming the Tide of Coastal Fish Habitat Loss. Proc. 14th Annual Marine Recreational Fisheries Symposium, Baltimore, Maryland. National Coalition for Marine Conservation, Savannah, Ga. 258 pp.*
- Turner, R. E. 1994. Landscapes and the coastal zone. Pp. 85-106, In: *Environmental Science in the Coastal Zone: Issues for Further Research. National Research Council. National Academy Press, Washington, D.C. 172 pp.*
- Turner, R. E. 2001. Of manatees, mangroves, and the Mississippi River: Is there an estuarine signature for the Gulf of Mexico? *Estuaries* 24: 139-150
- Turner, R. E., and M. S. Brody 1983. Habitat suitability index models: northern Gulf of Mexico brown shrimp and white shrimp. U.S. Dept. Interior. Fish and Wildlife Serv. FSW/OBS-82/10.54. 24 pp.
- Turner, R. E., W. W. Schroeder, and Wm. J. Wiseman, Jr. 1987. The role of stratification in the deoxygenation of Mobile Bay and adjacent shelf bottom waters. *Estuaries* 10: 13-19
- Turner, R. E. 1992. Coastal Wetlands and Penaeid Shrimp Habitat, pp 97 - 104. In Stroud, R. H. [ed.], *Stemming the Tide of Coastal Fish Habitat Loss, Proc. 14th Annual Marine Recreational Fisheries Symposium, Baltimore, Maryland, National Coalition for Marine Conservation, Savannah, Georgia.*
- Turner, R. E., and N. N. Rabalais 1991. Changes in the Mississippi River water quality this century - Implications for coastal food webs. *BioScience* 41: 140-147.
- Turner, R. E., and N. N. Rabalais 1994. Evidence for coastal eutrophication near the Mississippi River plume. *Nature* 368: 619-621.
- Turner, R.E., N. N. Rabalais, N. Atilla, C. Normandeau, B. Fry, J. M. Lee, C. S. Milan, T. A. Oswald, E. M. Swenson 2001a. *Paleo-Reconstruction of Water Quality in the Charlotte Harbor Estuary (Florida). Final Report, Southwest Florida Water Management District, Tampa, Florida. 70 pp., 4 appendices.*
- Turner, R. E., E.M. Swenson, and C.S. Milan 2001b. Organic and inorganic contributions to vertical accretion in salt marsh sediments. Pp. 583-595 In: M. Weinstein and K. Kreeger (eds.). *Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishing, Dordrecht, Netherlands. 864 pp.*
- U.S. Geological Survey 1985. *The National Atlas, shoreline erosion, and accretion map. U.S. Government Printing Office, Washington, D.C.*
- Wiseman, Wm. J., Jr., E. M. Swenson, and J. Power 1990. Salinity trends in Louisiana estuaries. *Estuaries* 13: 145-154.

CHAPTER 4. POTENTIAL FATE OF MARITIME FOREST RESOURCES: Major Findings of the Maritime Forest Sector Case Studies



- 4.1 Current Status and Stresses of Gulf Coast Maritime Forests
- 4.2 Vulnerability of Gulf Coast Maritime Forests to Climate Change
- 4.3 Forecasting Maritime Forest Retreat from Climate Change
- 4.4 Socioeconomic Implications of Gulfwide Forest Losses
- 4.5 Challenges and Opportunities (Response, Coping/Adaptation Options, Information and Research Needs)

The forest resources of the Gulf Coast region provide many valued functions and services for wildlife, and society, including among others, recreational opportunities, flood storage and habitat. Gulf Coast forests are also a major source of forest products on a national scale and are of great importance to the economy and society of the South. Climate change poses some immediate and long-term changes, some positive and some negative, to the health, function, and biodiversity of maritime forests along the coastal margin of the Gulf of Mexico. Some human activities including coastal development, urban expansion, and forest conversion presently contribute to fragmentation and other alteration of coastal forests that may exacerbate their vulnerability to climate change. Maritime coastal forests also have some climate-induced stresses, notably sea-level rise and hurricanes to deal with, that make them more vulnerable than many inland forests to a changing climate. On the other hand, increasing levels of CO₂ in the atmosphere will likely increase forest productivity on a continental scale and increase forest inventories across the Southeast. Forests of the Gulf Coast region are intensively cultured and as a result have the potential for significant carbon dioxide assimilation and carbon sequestration, which contributes to increasing forest productivity and also helps to reduce the CO₂ levels in the atmosphere.

Coastal reaches of the Gulf of Mexico region are fairly undeveloped as a whole with substantial acreage under public protection in state and federal preserves. However, their physiographic position at the land-sea interface makes them vulnerable to offshore and onshore environmental changes. Sea-level rise is projected to increase over the next century causing coastal erosion and saltwater intrusion that can lead to habitat loss and maritime forest decline. Hurricanes should become more intense with increasing sea-surface temperatures, which will cause greater forest damage and turnover per strike thereby increasing opportunities for invasive species recruitment and forest displacement to aquatic or emergent ecosystems. Extreme precipitation and drought episodes are projected to occur more frequently in the future that may lead to compositional shifts toward more drought-tolerant tree species. Higher temperatures and less frequent freeze episodes could be both positive and negative, altering the mix of temperate and tropical species diversity and increasing the spread and abundance of invasive species. Increasing drought frequency may also result with warming trends and foster increasing fire disturbance.

This chapter focuses on the potential consequences and challenges of climate change that are posed on maritime forests of the Gulf Coast region. We reviewed the various case studies of climate change impacts on Gulf Coastal forests by region and ecosystem type. A synthesis of the case study results and Gulf Coast county population growth, salt marsh area and tidal dynamics was used to assess the potential fate of maritime forest losses under climate change from projected sea-level rise. The potential impact of other climate-induced stresses on ecosystem resiliency, regional economics, and society are discussed.

4.1 Current Status and Stresses of Gulf Coast Maritime Forests

Coastal environments are among biologically diverse and productive terrestrial ecosystems. Changes in sea level, hurricane activity, invasive species, freshwater runoff quality and quantity, and economic development impinge on these valued systems and their economics. Coastal margins serve as nursery grounds for fisheries and habitat for wildlife as well as storm buffers and recreation for society. Anthropogenic coastal development pose the greatest irreversible threat to wetland loss, but natural changes and disturbances can also render short and long-term losses.

Climate fluxuation from ice ages to warming periods have effected sea levels and coastal extent and ultimately the ecosystems in those locations, as evidenced from geologic records. Currently, global sea level is on the rise. Rising sea-level is already affecting our coastal resources to an extent that society must deal with the impacts and losses. Maritime forests of all types across the Gulf Coast currently show some evidence of forest decline from saltwater intrusion attributed to sea-level rise and hurricanes. Non-native tree species imported for horticultural uses have infiltrated natural settings and altered forest structure and dynamics to a lesser or greater degree. The tolerance of some exotic tree species to flooding and salinity has resulted in near complete displacement of native forests in specific places along the Gulf Coast.

Human activities can affect coastal margins both directly and indirectly, and nearby and many miles away. Direct conversion of freshwater and tidal wetlands for other purposes such as agriculture development of lakes and reservoirs, and urban development reduces flood storage, storm buffering, and conservation zoning among other important services. When wetlands are converted, flood waters and storm impacts are distributed elsewhere such that adjoining wetlands become overly stressed. Societal infrastructure can also be overly exposed to flood damage with severe economic ramifications. Runoff from fertilized agricultural lands and non-point source wastewater disposal has contributed to nutrient-enriched river systems and nearshore hypoxic zones in the Gulf of Mexico. Therefore, solutions to protecting coastal margins may necessitate comprehensive planning that includes both local and regional watershed concerns.

4.1.1 Sea-level Rise and Coastal Subsidence: Trends and Projections

Coastal areas of the Gulf Coast and worldwide are slowly being inundated by rising sea levels. Warming of our global environment threatens to speed the rate of current sea-level rise and perhaps further amplify the detrimental effects of tropical storms, droughts, and lightning caused fires. Sea levels have reportedly been rising since the last ice age (15,000 B.P.) and over the last century by as much as 1-2 mm/year. The latest Intergovernmental Panel on Climate Change (2001) has projected a 50 cm rise in average global eustatic sea level by the year 2100 within a probable range of 15 - 95 cm given some uncertainties. Other conservative estimates by the Environmental Protection Agency indicate that global warming will likely raise sea level by at least 42cm by 2100. While long-term tide gauge records for the Gulf Coast and worldwide exhibit increasing sea levels during the 20th century, there is yet insufficient evidence of any significant acceleration trends related directly to greenhouse gas emissions.

These sea-level projections do not consider increases in relative sea level by region affected by local factors other than warming sea temperatures such as land subsidence. Relative sea level is the effective change in the land/water relationship at a given site that includes both the eustatic sea level change condition and changes in surficial elevation and accretion. Gulf Coast wetlands, in particular, have shown high rates of land subsidence attributed to soil decomposition and compaction, deep fluid extraction, and the lack of allochthonous sediment deposition. For example, the Mississippi River delta region demonstrates relative sea-level rates of 10 mm/yr, tenfold greater than current eustatic sea-level rise. Subsidence rates have been measured for several Gulf Coast sites ranging from a low of 0.27 cm/yr in the Big Bend region of northwest Florida up to 2.39 cm/yr for coastal Louisiana. Some of the forces driving shallow subsidence apparently included seasonal changes in water levels and periodic occurrences of major storms.

In order for maritime forests not to become submerged as sea-level rises, soil accretion by organic root production or inorganic deposition must equal or exceed the rate of relative sea level change. The potential for coastal submergence is controlled more by the local environmental factors of regional subsidence and geomorphology, sediment loading and distribution, and frequency of major storms than by the long-term trends of rise and fall in eustatic sea level. Soil accretion rates for a suite of Gulf Coast sites have been monitored over the last decade and have shown to keep pace with relative sea-level rise.

Other hydrological and climatological forces can affect short term rises and falls in relative sea level that may be critically important to how wetlands in a given coastal reach tolerate submergence. Seasonal changes in prevailing winds and freshwater outfall along with periodic occurrences of tropical and extratropical storms can influence prolonged flooding and saltwater intrusion, that can effect forest dieback and transgression. Extreme droughts, floods, and fronts may play a greater role in affecting coastal change than what has previously been documented particularly in low relief systems where decimeter changes in the tidal prism and flooding norms can result in wide-area wetland submergence. Episodic incidences of this kind during epochs of unidirectional sea-level rise may prohibit ecosystem recovery and promote coastal transgression.

4.1.2 Hurricanes and extratropical storms: trends and projections

Scientists are evaluating the links between global warming and hurricanes; some suggesting that the recent rise of hurricane incidence in the 1990's for Atlantic basin storms could be the beginning of a global ENSO cycle of increased hurricane activity. Projected increases in sea surface temperatures are expected to fuel greater hurricane intensities proportional with temperature rise. As yet, there are no discernible global trends with respect to frequency, intensity, or location of hurricanes to offer any empirical evidence of changing hurricane patterns this century. Whether hurricanes increase in frequency or intensity in the future as a result of climate change or not, they are agents of acute disturbance that cumulatively influence coastal change and may interact with rising sea level to speed coastal retreat. Even though tropical and extratropical storms are far less catastrophic, they can contribute to acute and chronic stress through inland flooding and salinity pulsing. Extratropical storms can also cause significant damage directly or with depositional surpluses. Intense rainfall events often result from these weather systems and can cause flooding sufficient to drown trees in poorly drained basins causing episodic forest diebacks.

Hurricanes pose a severe threat to natural systems and public safety. Hurricanes accounting for more property losses than other comparable hazards, such as earthquakes, volcanoes, and wildfires. Whereas loss of life from hurricanes has decreased in recent decades, property losses due to rapid population growth and economic development of coastal areas has increased. Hurricanes have their greatest impact at the coastal margin where they make landfall and sustain their greatest strength. Severe beach erosion, overwash deposition, and windfall casualties are exacted on the physical and biological constituents of nearshore and onshore ecosystems. There is a rather extensive literature base of case studies that describe the severe impact and recovery of tropical and temperate ecosystems for particular hurricanes along the Gulf Coast. Whereas the impact of hurricanes increases with hurricane strength and intensity, the sensitivity of some biota may vary for equal storm effects. Also, similar ecosystems in different coastal locations experience greater or lesser recurrence of hurricanes based on historical trends.

Gulf Coast ecosystems are exposed to varying degrees of hurricane disturbance as influenced by storm frequency, periodicity, and duration. Landfall frequency estimates of tropical storms across the Gulf of Mexico basin increases geometrically from west to east, Texas to Florida. Because most storms spawn in tropical waters in the eastern Atlantic there is a greater probability for eastern landmasses on the same latitude to incur tropical storms. However, hurricane distribution within the region is much more disjunct, with coastal sections in the western and eastern Gulf of Mexico that experience below average landfall rates. Temporal patterns of hurricane frequency by decade and quarters of the past century exhibited significantly active and inactive periods. The relatively calm period of record for hurricanes from the 1950's through the 1970's, has some hurricane specialists purporting an increase in North Atlantic storms over the past decade related to ENSO oscillations and general warming trends. Palynological and geological studies offer another means to reconstruct the history of hurricane activity over several centuries coincident with species changes and sedimentary overwash indicative of surge heights and storm intensity. Projections from these type of studies in the Gulf Coast region suggest that the 20th century record of storms may be relatively tame compared to past millennia.

4.2 Vulnerability of Gulf Coast Maritime Forests to Climate Change

The Gulf Coast region encompasses temperate and tropical climate regimes and species diversity. Prominent maritime forest types vary with substrate types of marine and alluvial origins including mangrove, cypress-gum swamps, hardwood hammocks and bottomlands, and pine-palmetto associations. The geology and soils include a diversity of mostly saturated environments supporting sandy beach ridges, flatwoods, cheniers, barrier islands, rich alluvial bottoms of river deltas, and marl and peat deposits underlain with karst limestone. Most of the coastline across the Gulf of Mexico basin can be characterized as stable excepting the Louisiana Deltaic and Chenier Plains that have been undergoing alarming rates of coastal erosion and wetlands loss in recent decades (Figure 1).

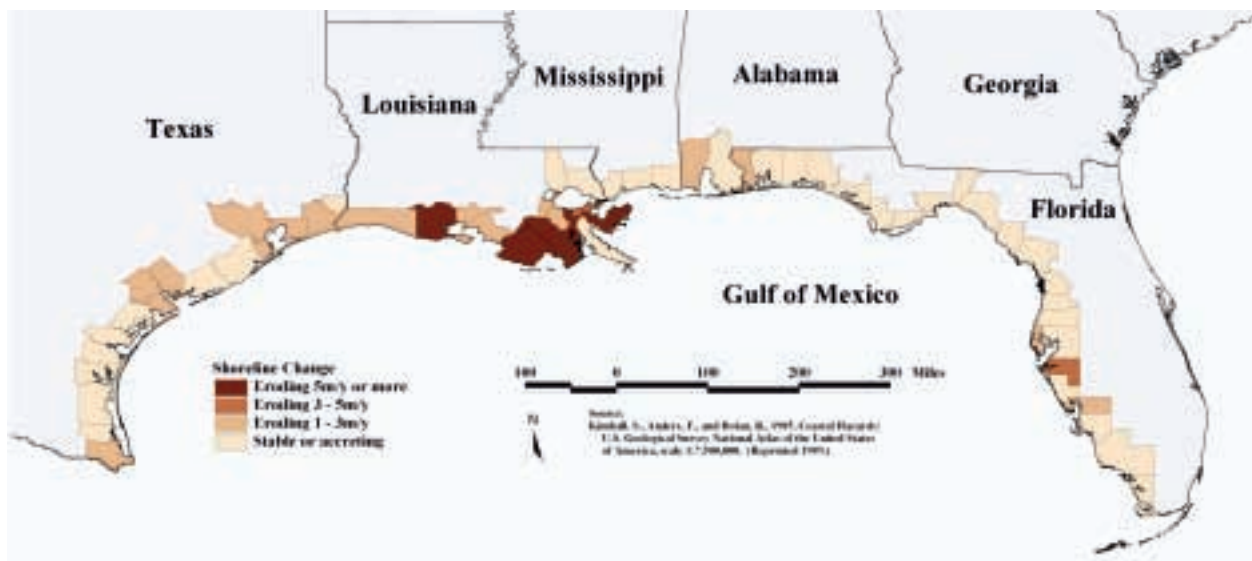


Figure 1. Coastal erosion rates for all coastal counties and states for the Gulf of Mexico region modified after Kimball et al., 1985).

Hydrological characteristics of these low-relief forest settings include some degree of coupling with coastal waters as dictated by tides and freshwater forcing. Mangroves are halophytes capable of tolerating saltwater and persisting in intertidal zones, whereas the pine, oak, and cypress dominated forest associations are susceptible to prolonged or concentrated exposures of salinity. Coastal reaches of the Gulf of Mexico also vary in the degree of wave energy, tide types, and range. Wave energy is classified as “zero” from St. Marks River east along the Central Florida coastline to Cedar Key, Florida and moderate from St. Marks River west to Texas and for much of south Florida. Tidal range varies from less than 1 m west of the St. Marks river along the northern coast and between 1-2 m south to the Everglades (Figure 2). The unique hydrologic and geomorphologic characteristics of each setting predetermines the success and susceptibility of the type of maritime forest and associated species. Slight changes in the forcings of freshwater and saltwater relations as influenced by climate change (e.g., droughts, hurricanes, sea-level rise, etc.) can disturb and destroy maritime forest.

Sediment cores of maritime soils often reveal the cyclic process and periods of coastal expansion and retreat in the geologic record. Layers of different or alternating peat deposits from forest, marsh, and marine origin can be aged and related to the rate and changing

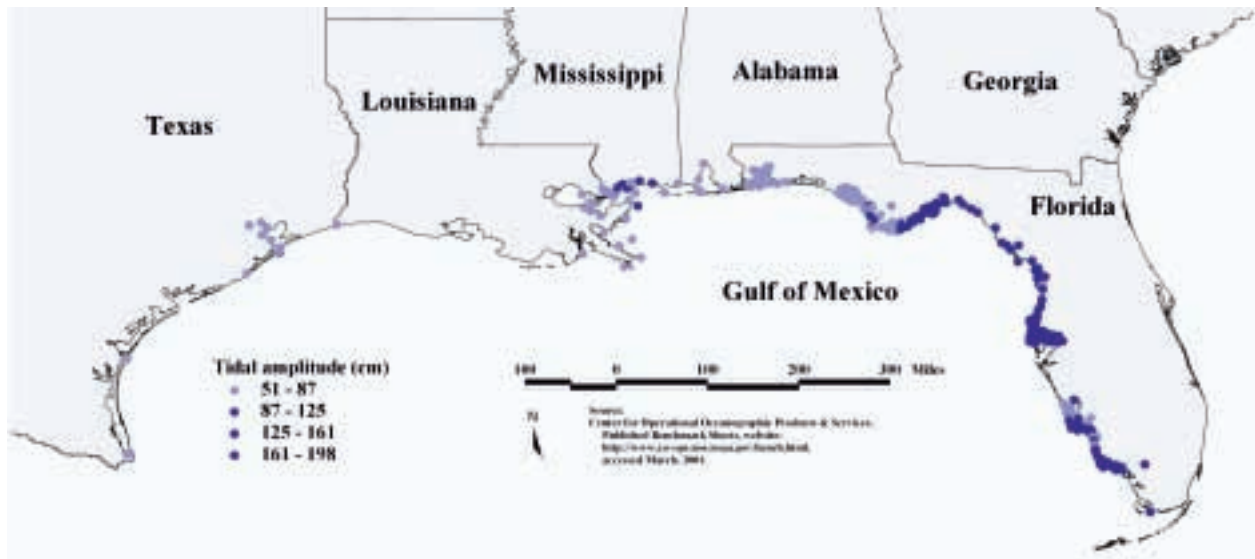


Figure 2. Tidal range (MHHW-MLLW) for NOAA tide stations along the Gulf Coast of Texas, Louisiana, Mississippi, Alabama, and Florida.

direction of historic sea levels. Contemporary evidence of stressed maritime forests along the Gulf Coast seem to indicate that current sea level changes may be changing sufficiently or rapidly enough to cause forest dieback and retreat. Forest dieback represents an acute or chronic disturbance that compromises forest health and vigor sufficiently to cause massive tree mortality. Certain species may be more or less sensitive in that they die sooner or later depending on the environmental cause and conditions. Coastal retreat or transgression is the process of ecosystem displacement from a forested system to another type such as marsh or open water.

4.2.1 Sea-level Rise and Coastal Retreat

The mechanisms for spurring coastal retreat are usually hydrological in nature involving acute and prolonged flooding, saltwater intrusion, or wave erosion. Mangrove forests in basin settings or coastal impoundments can experience partial or complete forest dieback when static water levels are raised abruptly and sufficiently above normal levels that compromise lenticel function and oxygen uptake. These episodes can occur with excessive runoff or rainfall events in catchments where drainage is blocked or inadequate to reduce water volume over a period of days. Prolonged ponding from beaver, sedimentation, or human activity where catchment outlets are impinged can cause similar dieback in bottom-land hardwood systems. Saltwater intrusion into maritime systems other than mangroves will eventually raise soil salinity enough to kill all other tree species with or without increasing the hydroperiod. A single salt pulse or cumulative overwashes can kill even hardy pine species that tolerate salt spray environments. The death of low elevation pines in recent years in the Florida Keys that persist on freshwater lenses is attributed to increasing sea level perhaps exacerbated by local drought or freshwater withdrawal by humans. Lowland pine woodlands and hardwood hammocks in Central Florida gulf coast estuaries have retreated in parallel tracts of progressive mortality waves by species and size class from increasing tidal inundation over periods of decades. Standing snags of dead cypress swamp dot the Louisiana coast and chronicles the intrusion of saltwater in a rapidly subsiding deltaic system. Relict stumps and stands of all species can be found in saltmarsh and mangrove zones marking the migration and encroachment of forest edge across the Gulf Coast over the last century.

4.2.2. Hurricanes and Coastal Retreat

Hurricanes generate high winds and wave action that can scour soils and beaches and topple whole forests. Numerous field studies across the Gulf Coast region have documented the susceptibility and vulnerability of maritime forests of all types. The type and extent of forest damage, windthrow, branch loss, and defoliation is primarily related to wind force though storm direction, but stand sheltering, and species resistance can dictate the degree of impact. Excessive leaf litter loading into surrounding aquatic systems can increase oxygen demands and cause hypoxic conditions and fish kills lasting weeks and months after a hurricane strike. Blowdown sites in mangrove systems without survivors can undergo rapid root decomposition and substrate collapse sufficient to inhibit subsequent regeneration causing permanent forest retreat. Salinization from high storm tides and surges can infiltrate and pond in backwater swamps and beach swales and cause delayed mortality even if standing trees withstand direct wind force. Dune scouring and deposition on barrier islands and beach terraces can expose or bury trees and forests, which can compromise root function and lead to delayed mortality.

4.3 Forecasting Maritime Forest Retreat from Climate Change

Developing tools to predict the vulnerability of coastal margins to change from human-induced and natural factors is paramount for exploring coping strategies and engineering alternatives. Computer simulation models that mimic coastal processes and retreat are needed to evaluate the potential losses, or gains, of services and feasible alternatives for ameliorating any impacts. Several ecological models have been developed for U.S. coastal systems to evaluate water management alternatives and climate change scenarios. While the modeling approaches and objectives vary, they all spatially articulate the landscape and predict how changes in hydrology, salinity, and geomorphology could affect habitat succession and distribution. In all cases, sea-level rise and tropical storms are expected to cause wetland loss or retreat as dictated by the local environmental setting.

4.3.1 Modeling Mangrove Migration across South Florida

Forest models have been developed to predict how changing climate could influence forest succession and distribution in Gulf Coast maritime forests. Applications of the SELVA-MANGRO model were used to forecast the effects of increasing sea level and hurricane activity on the structure and distribution of mangrove communities of south Florida. The SELVA-MANGRO model represents a hierarchically integrated landscape model that manages the exchange of scalar information up, down, and across scale between linked simulation models SELVA and MANGRO. A digital elevation model of the Everglades was interpolated to track the process and pattern of coastal inundation over space and time for various projections of sea-level rise within SELVA. MANGRO predicts the tree and gap replacement process of natural forest succession of mangrove species as influenced by stand structure and environmental conditions. Composite maps are produced that exhibit the predicted changes in species composition and forest migration, loss or gain, as influenced by changes in sea-level. Model results show that species and forest cover changed over space and time with increasing tidal inundation across the simulated landscape for all sea-level rise scenarios. The greater the rate of sea-level rise the faster or more extensive the

encroachment of mangroves onto the Everglades slope. The model shows that freshwater marsh/swamp habitats will be displaced as the tidal prism increases over time as it moves upslope. Under these modeling assumptions, mangrove habitat will increase over the next century under climate change and conversely, freshwater marsh/swamp is expected to decrease.

4.3.2 Predicting Coastal Pine-Palmetto Forest Retreat in Northwest Florida

Unlike mangrove species and systems that tolerate and thrive in saltwater, other Gulf Coast maritime forests are intolerant to saltwater flooding. A regional site application of a GIS-based simulation model, WETLANDS, was developed to predict ecosystem response to changing sea-level conditions on a coastal reach of the Big Bend region in northwest Florida. Land elevation and tidal inundation are key factors controlling vegetation relations and ecotonal boundaries on this landscape. The WETLANDS model contains probabilities of community tolerance to flooding conditions that dictate the rate and process of ecological succession and coastal retreat. Map information of hypsography and bathymetry of the study area were digitized and interpolated to construct a digital elevation model of the coastal landform. Model simulations were generated to predict a likelihood index of habitat change and conversion under different scenarios of sea-level rise. Model results indicated that major portions of this coastal zone will be permanently inundated by 2100, bringing about a combined migration of marsh habitat and displacement of maritime forest. Results show that lowland pine forests of the Big Bend coastal reach will undergo retreat on the order of thousands of hectares over the next century.

4.3.3. Gulfwide Model Projections of Coastal Retreat

Detailed elevation models of the coastal zone below the 5-ft contour line do not exist across the Gulf Coast except for select parks and refuges like Everglades and the Big Bend region of Florida. Therefore, a GULFWIDE model was developed to predict maritime forest dieback as a result of projected sea-level rise based on a proxy relationship of saltmarsh area and tidal range by county for all Gulf states. As sea-level rises, flooding and salinity intrusion will increase with slope at the coastal interface. The GULFWIDE model assumes that the sum area of saltmarsh along any given coastal reach is determined by the slope of the landform and vertical tide forcing. Coastal zones with nominal saltmarsh area and high tidal range are indicative of steep dunes or eroding cliffs with little potential to migrate and displace adjoining forest edge, whereas expansive saltmarsh area and low tidal range akin to Louisiana's coast and Everglades indicates a low relief coast with high potential to encroach upslope with even small increments of sea level change. Fresh marsh systems lie in a transition zone between saltmarsh and forest. This transition zone is largely controlled by freshwater forcing from riverine, groundwater seeps, and atmospheric sources. The model assumes that fresh marsh systems will remain in equilibrium within each local setting and migrate concomitantly with saltmarsh as sea level changes.

The Gulf of Mexico coastline was subdivided into separate reaches assigned by each of 60 coastal counties from Texas, Louisiana, Mississippi, Alabama, and Florida. Area estimates of saltmarsh extent for each county was obtained from published sources based on aerial photography delineations and wetland databases like the National Wetlands Inventory (Figure 3). Tidal ranges were obtained from a NOAA tide stations database for more than

300 locations and filtered to assign corresponding maximum tide range for each county (Figure 2). An algorithm was devised to predict the potential for maritime forest dieback based on the proportion of sea-level rise and tide range to saltmarsh area. This procedure produced an estimate of average forest dieback or retreat.

Climate change scenarios were evaluated for low (15 cm), mid (50 cm), and high (90 cm) sea-level rise projections over the next century. The potential for forest acreage loss was calculated by county. State and gulfwide values for potential forest acreage loss were calculated by summing across county values. Model results indicated that saltmarsh and mangrove migration across the Gulf Coast, which will permanently displace as much as 640,000 ha of maritime forest by the year 2100 with a near meter rise in sea level (Figure 4). Most of the estimated coastal retreat is expected in Louisiana alone approximating, 70 percent of the Gulfwide losses or 440,000 ha (Figure 5). The Louisiana delta may provide a special case that may well overestimate the real threat given all the constructed levees that protect swamp forest and agricultural lands from flooding by saltwater intrusion. These estimates could also underestimate future conditions since the model does not account for local subsidence rates. Figure 6 shows the projected land loss by coastal retreat for each county and state across sea-level rise scenarios. In all, significant acreage of maritime forests will be displaced even at the lowest projection for sea-level rise and thereby impose both ecological and economic costs across the region.

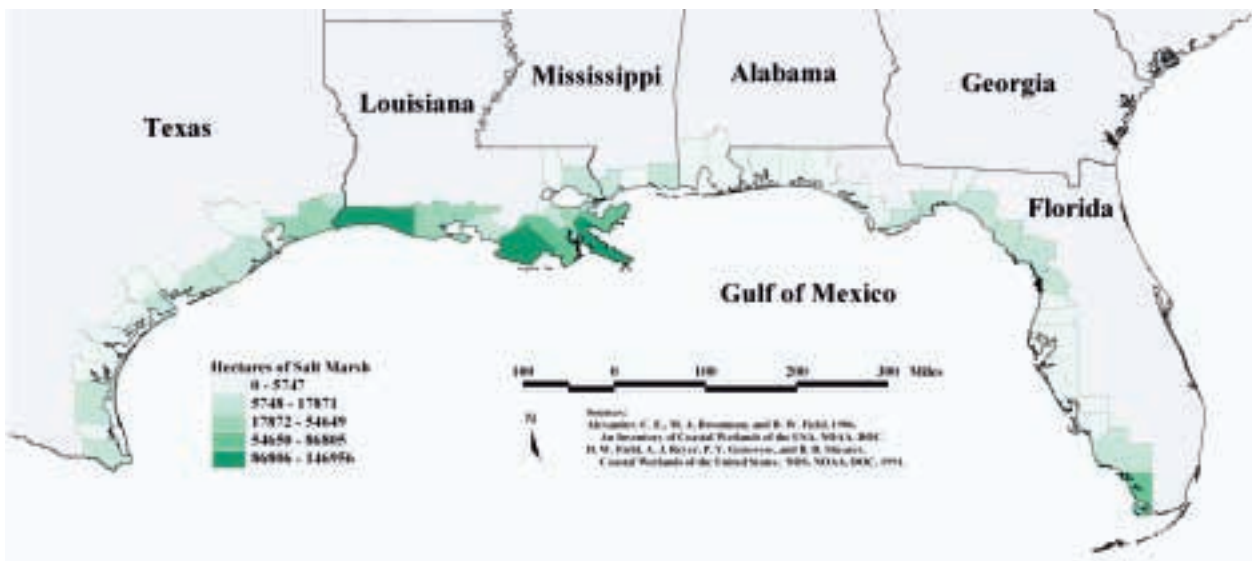


Figure 3. Saltmarsh area (ha) for each county and state along the Gulf of Mexico based on National Wetlands Inventory sources compiled by Field et al., 1991.

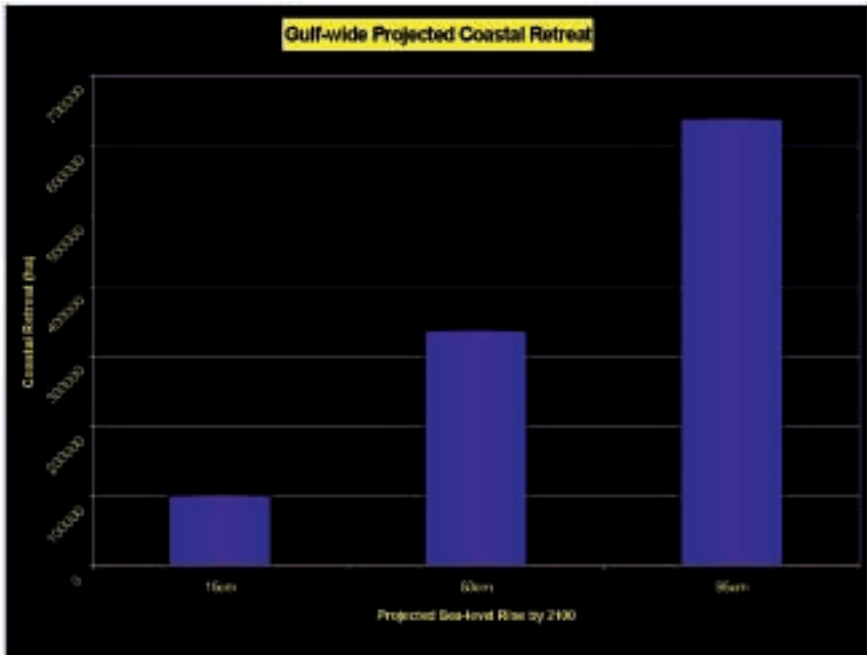


Figure 4. Projected losses (ha) of maritime forest by coastal retreat for the entire Gulf Coast for a low, mid, and high estimate of eustatic sea-level rise by the year 2100.

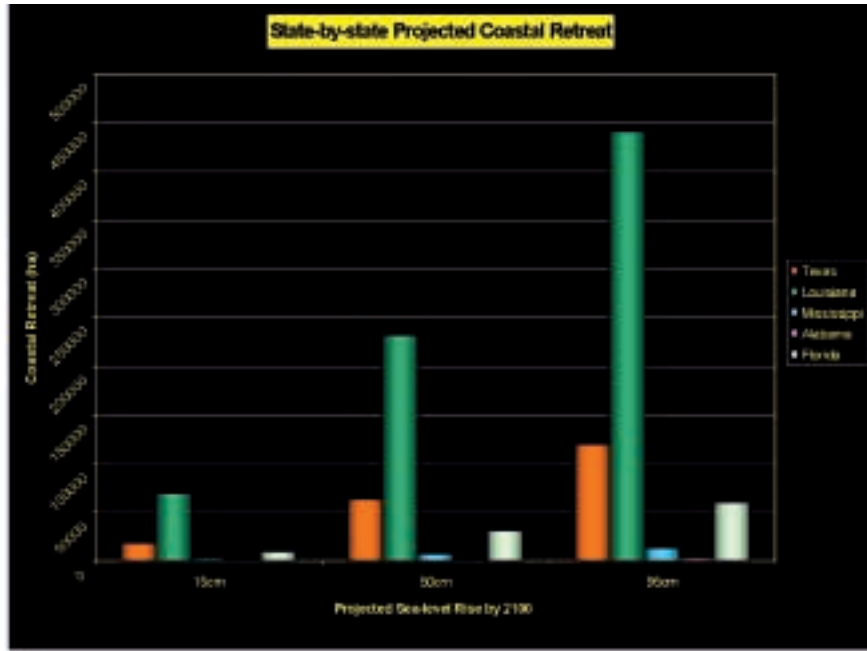


Figure 5. Projected losses (ha) of maritime forest by coastal retreat for the entire Gulf Coast illustrated for each state for a low, mid, and high estimate of eustatic sea-level rise by the year 2100.

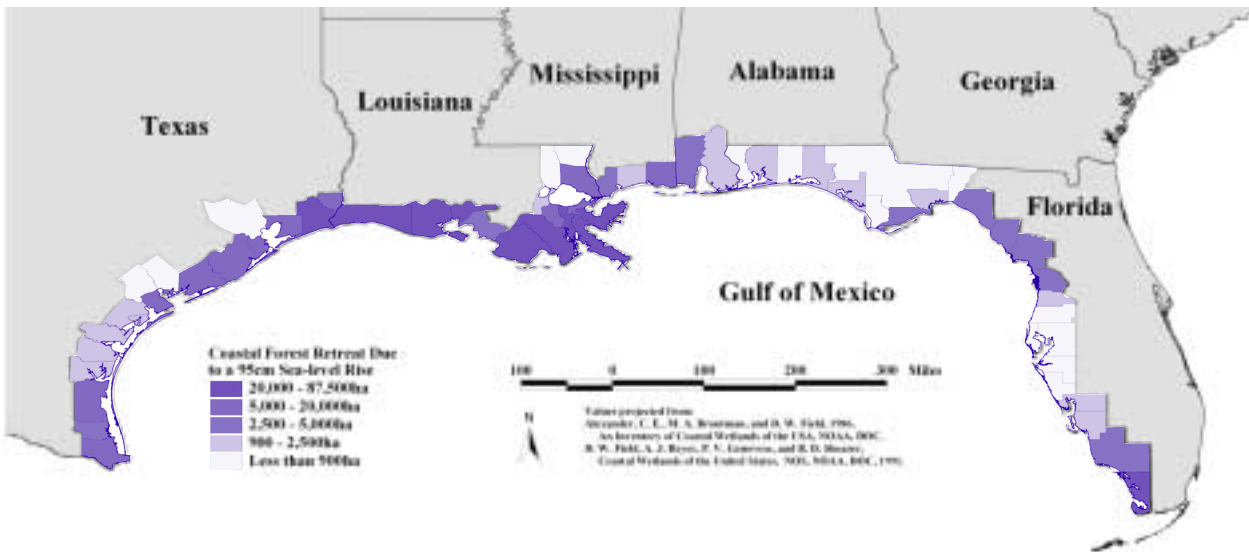
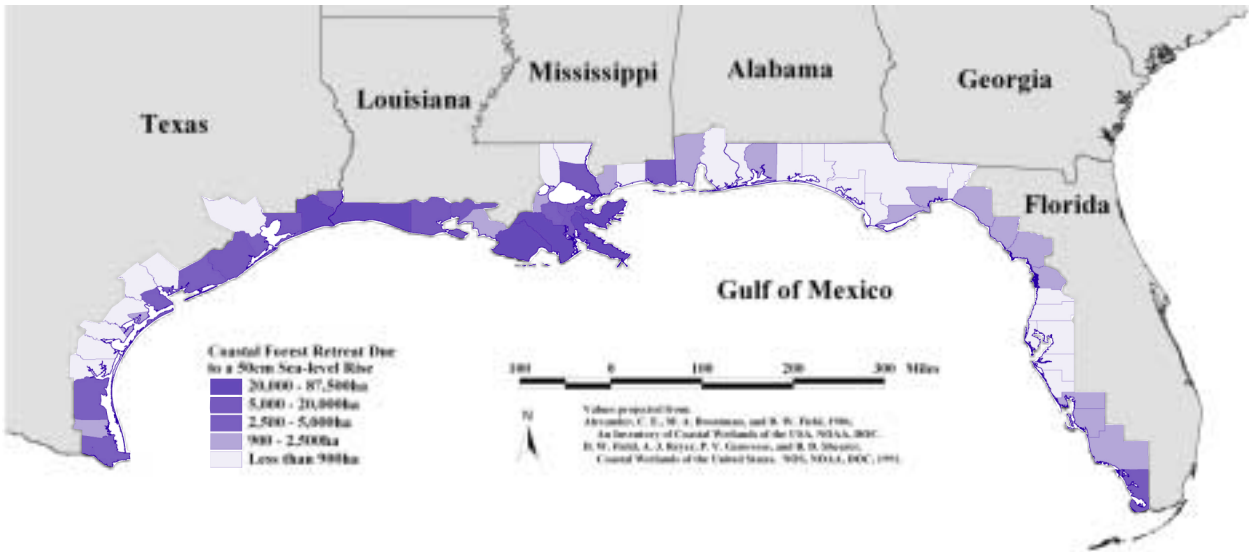
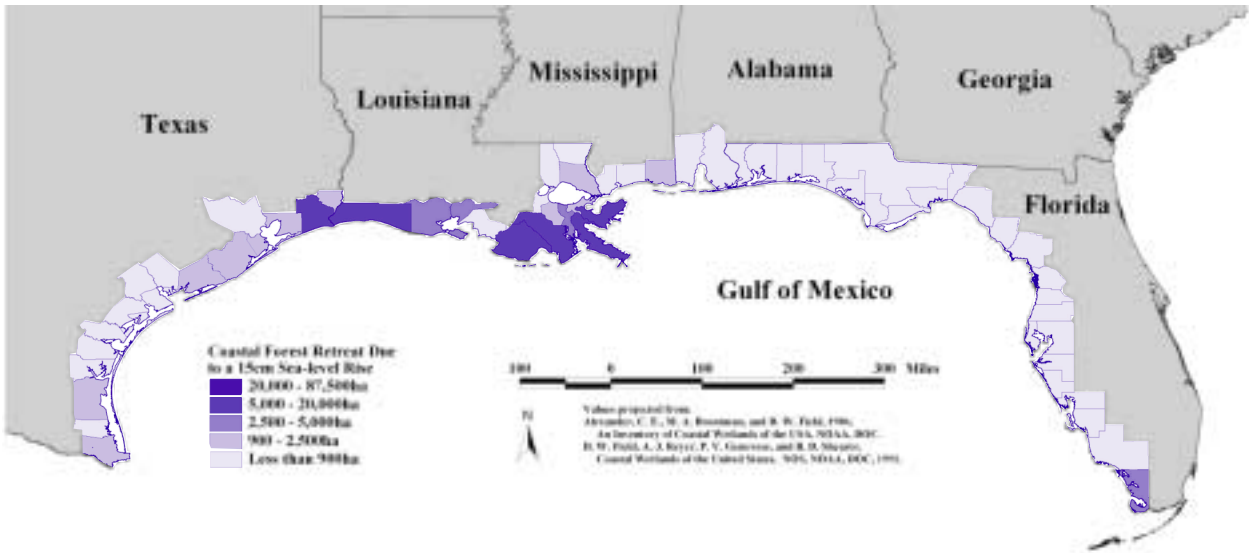


Figure 6. Predicted coastal forest retreat based on GULFWIDE simulation model for all counties and states along the Gulf Coast for climate change scenarios of 15, 50, and 95 cm rise in sea level by year 2100.

4.4 Socioeconomic Implications of Gulfwide Forest Losses

Forest inventories across the Southeast and Gulf Coast region are likely to increase with increasing CO₂ levels from climate change. In contrast, the maritime forest sector will endure dieback and replacement by invasive species and saltmarsh if global sea-level rises by any degree. Acreage losses will reduce the potential timber and forest product resources available for economic utilization. But, though maritime forests are valued more for recreation and wildlife than commercial forestry. Invasive tree species will further degrade the quality of timber resources and wildlife value of stressed native tree populations excepting mangrove zones. Conservation areas, parks and refuges, along the Gulf Coast will lose real estate that will decrease the functional value of aesthetics for humans and habitat for some wildlife species. Where thin coastal strands of maritime forests serve as storm buffers along for public and private lands, the vulnerability of homes and businesses will be put at risk without costly engineering alternatives. Recreational opportunities will be affected to a lesser degree by loss of public access or hunting success.

Population projections for the Gulf Coast by the year 2025 are far above national averages (Figure 7). Current population growth rates (Figure 8), if sustained, will involve further

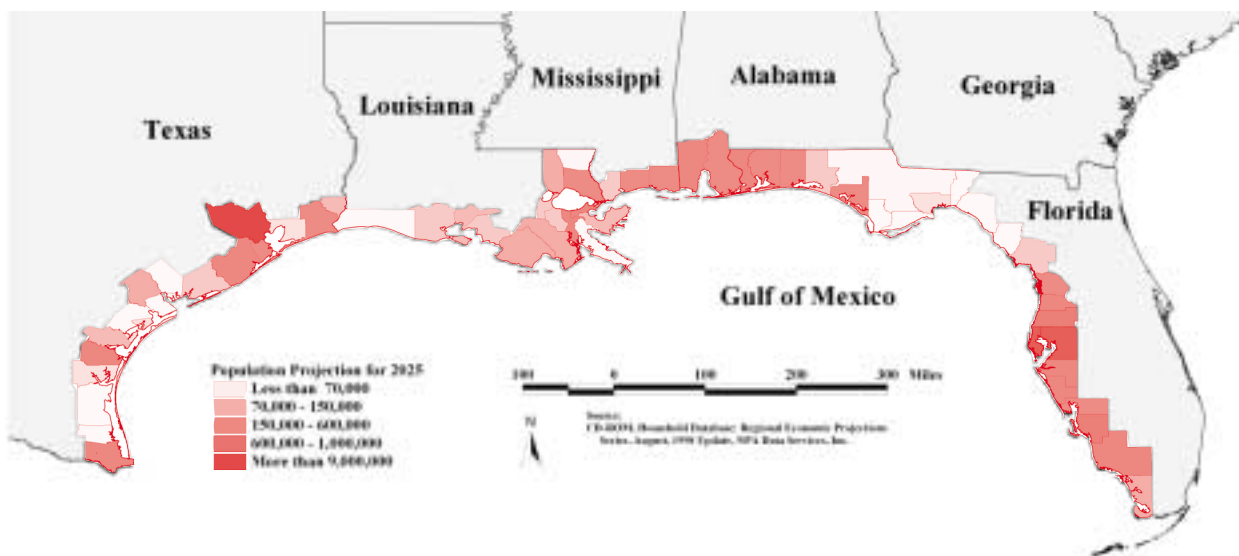


Figure 7. Projected human population estimates for Gulf Coast counties and states by the year 2025.

development of coastal real estate in the private sector. The burgeoning growth of south Alabama and Florida will undoubtedly place a high demand on public resources, electricity, water, land, etc. Conversion of forest and marsh habitat will cause reduction in ecological services and commercial returns of both the forest and fisheries industry. Water resources may be the first and most critical resource that will likely impinge on surrounding conservation areas and coastal preserves. In the absence of mitigating strategies changes in freshwater storage and flow, above and below surface, will indirectly, if not directly, speed the effect and extent of sea-level rise. Consequently, the public demand for potable water supplies must be met by other means such as desalination plants and other conservation measures.

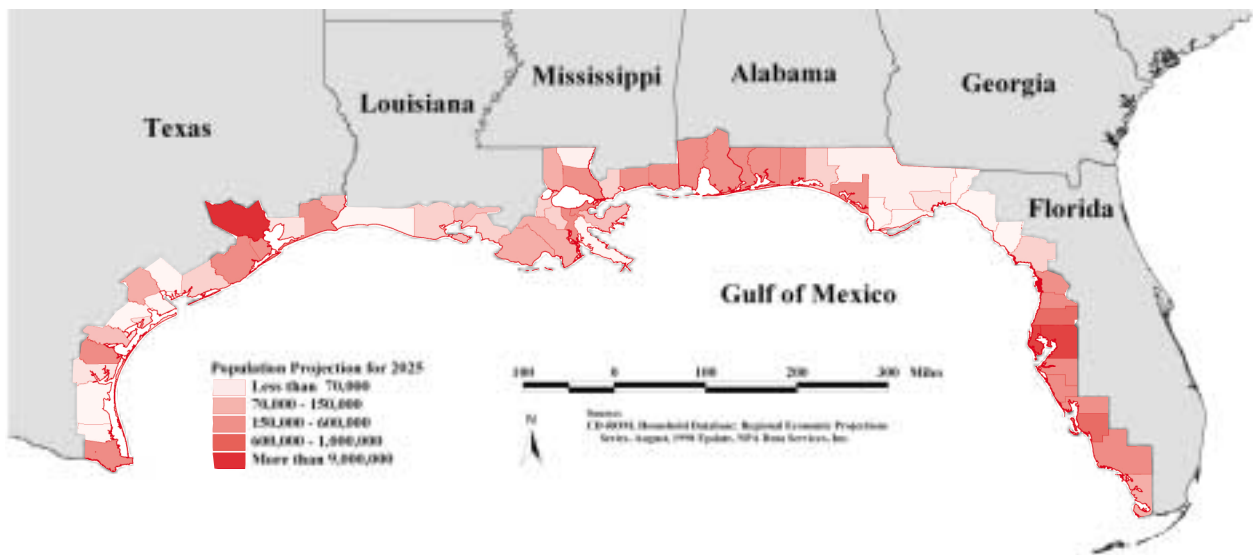


Figure 8. Projected population growth rate by county and state for the Gulf Coast region.

4.5 Challenges and Opportunities (Response, Coping/Adaptation Options and Information and Research Needs)

Potential climate change impacts to maritime forest resources of the Gulf Coast region will command both challenges and opportunities for public and policymaker response to address coping strategies and research needs. Because most of the coastal zone of the Gulf Coast is already in the public trust of state and federal lands, private interests are largely buffered from any immediate threats or costly infrastructure that is not already in place to protect economic interests. Undeveloped coastal property under private ownership will be under increasing pressure for economic development with population growth in coastal counties expected to increase over the next century. Education of potential climate change impacts of hurricane incidence and sea-level rise represents the first line of defense that can be applied to engage stakeholder and government responsibility. Adaptation strategies will vary with coastal type and threat but will involve decisions to remedy, reduce, or retreat in preparation of coastal change.

Contemporary forest dieback and predicted coastal retreat provide the basis for assessing the degree and timing of potential impact that may help prioritize the threats and feasibility to develop comprehensive coastal planning schemes by county and state for minimizing realized impact. Coastal parks, refuges, and reserves under state and federal management have sufficient inland holdings in most cases that costly protection measures will be problematic, and therefore discounted. The risk of functional losses of maritime forests in natural areas along the coastal interface are valued but may be economically dwarfed in contrast to commercial developments and private investments. Some climate change factors cannot be abated readily such as hurricane strikes without further advances in meteorological intervention. Insurance claims from recent major hurricanes, Hugo (1989), Andrew (1992), and

others have challenged liability coverages for the massive societal infrastructure now present in coastal reaches prompting calculated reductions of policy renewals and insurability for hurricane damage. Sea-level rise, on the other hand, is an incremental impact with more predictable certainty and circumstances that coastal planners can prioritize and schedule long-term coping strategies and protection measures.

Further research is needed to refine our understanding and predictive capabilities to identify the links of offshore and onshore factors that may exacerbate coastal impacts at local and regional scales and the optional measures for abating them. Coastal forests exist where there is sufficient areal substrate above a given water datum established by local tides and flooding conditions. Alterations in the tidal prism and flood storage by man or nature will effectively change for better or worse the resiliency of contemporary forest ecosystems to persist and the opportunity for native seeds or plantings to succeed. Scientific investigations are warranted to improve our knowledge base of species genetics to increase saltwater tolerance, ecosystem restoration to assist freshwater assemblage conversion to saltwater habitats, and innovative engineering solutions.

CHAPTER 5 REGIONAL ASSESSMENT METHODOLOGY



5.1 Assessment Approach and Methodology

Setting the regional baselines and scenarios

A sound understanding of current conditions and future trends is necessary for conducting any climate change impact assessment. Therefore, the first step of the assessment was the establishment of regional baselines and scenarios.

Baselines for the regional climate, human environment, and natural environment, and possible future scenarios were established based on the Workshop participants' input, literature, and scientific data. The three baselines were established simultaneously in order to describe current conditions in the region. The established current condition provided information for the projection of the future scenarios. The projected future climate scenario and human environmental scenario were synthesized to provide information for the projection of the natural environmental scenario. Information obtained from the baseline conditions and climate scenarios was used to assess the impact of climate change on the natural environment, human, society, and economy of the region.

Selection of two specific priority sectors: Coastal ecosystems and bottomland forests

This assessment investigated the implications of climate change on the natural environment of coastal ecosystems and maritime forests. The assessment of the impact on the natural environment provided information for understanding both the causes and impacts of societal responses to climate change. Also, the assessment of the natural environment was integrated with the assessment of the socioeconomic/human environment impact in order to provide a comprehensive understanding of the human dimensions of the change.

Literature review of the current condition of selected ecosystems, their socioeconomical significance, and the potential climate change impacts on the selected ecosystems

The extensive literature review enabled the team to access information on the current condition of the selected ecosystems, their socioeconomical significance, and the potential climate change impacts on these selected ecosystems. The potential consequences and impacts of climate variability and change on the region's natural and socioeconomic/human environment was assessed by integrating the following: 1) background information on the region's natural and socioeconomic/human environment, in which its people live; 2) the region's historical climate; and 3) likely changes in its future climate.

Summarizing the literature review and incorporating case study results as quantitative examples to illustrate and support the qualitative and quantitative information

We accomplished the research and assessment activities through case studies. The case studies added substance to the assessment by providing sound scientific data to support the impact predictions and analyses. Each case study was designed to answer questions that relate to a key issue. The specific ecological systems and locations of the case studies were chosen based on their representativeness of the Gulf Coast region. Through these case studies, team members have:

- Established baseline conditions,
- Described the role of the natural and human environment in the regional economy,
- Summarized the effects of current climate variability and change,
- Predicted future effects of climate variability and change,
- Analyzed the impact of human activity,
- Provided a qualitative assessment of the consequences on the region's economy,
- Developed management/adaptation/coping strategies, and
- Defined future research needs.

Conducting a qualitative assessment of the socioeconomic implications of the projected ecological changes through case studies

The major source for making the qualitative assessment was the current literature. Team members compiled information for the qualitative assessment by conducting a literature review. Team members presented the results of socioeconomic impacts from the case studies to stakeholders at meetings, and gathered information on the socioeconomic impacts that local community is currently experiencing and may experience in the future.

Generating, through case studies and outreach activities, an array of adaptation strategies that merit further investigation

The results of analytical work, outreach activities, and the outcomes obtained in the previous steps provided the information and input to accomplish this step. In the process of accomplishing the previous steps, the assessment team members assessed the vulnerability of people in response to the consequences of climate change, and developed coping strategies based on these consequences and related vulnerabilities. Through the case studies and the sectional assessment, scientists obtained a better understanding of what is known and what is unknown. Based on the findings, the future research needs were identified.

Defining coping strategies and future research needs based on the work described above and stakeholders input

In the process of accomplishing previous steps, two symposia, 2 meetings, 1 roundtable, 2 summer institutes, and numerous seminars were organized. These venues provided the stakeholders a forum for a discussion of coping strategies and the research needs. The

stakeholders input reflected the real needs of the people in this region. Questionnaires were distributed to obtain a broad input for the public on coping strategies and research needs.

Coping strategies and research needs were synthesized from the several activities and evaluated for consistency across activities and for feasibility. Candidate coping strategies were analyzed with respect to institutional constraints and other potential barriers to their implementation. Research needs were analyzed with respect to their compatibility with existing research programs and ranked in the importance of the needed research results.

Integration of information/results into regional assessment publications

Assessment results were combined and integrated prior to publication. Volunteers, identified as technical experts, conducted extensive technical peer review of the regional assessment publications for scientific and technical accuracy and validity. Provisions were also made for including general comments by the stakeholders. The review procedures were coordinated by the assessment Team Leader. The Team Leader provided a central distribution and receiving point for written reviews. The Team Leader was also responsible for responding to and documenting the responses to written review comments.

5.2 Assessment Team and Collaborative Partners

5.2.1. Assessment Team

Dr. Zhu Hua Ning is a Professor and the Director of the Gulf Coast Regional Climate Change Assessment Program at Southern University and A&M College, Baton Rouge, LA. She is also the Project Director of many research projects funded by the US Department of Agriculture, US Environment Protection Agency, National Aeronautics and Space Administration, Department of Energy, and the National Urban and Community Forestry Advisory Council. Her research projects focus on CO₂ sequestration, climate change assessment, O₃, NO_x, particle pollution, effects of soil flooding, forested wetlands, and bioremediation. She has published 6 books, a book chapter, and more than 50 research articles. She received The Faculty Award for Excellence for Outstanding Research Performance at Southern University College of Agricultural, Family and Consumer Sciences in 1996-1998 and 2000-2003. She has initiated and established collaboration between Southern University and the US Global Change Research Program, The USGS National Wetland Research Center, National Center for Atmospheric Research, and the Chinese Academy of Sciences. A significant portion of her research is concentrated on climate change assessment and ways to mitigate environmental problems. This led to her recognition in 1998 by the Director of the White House Office of Science and Technology Policies, Governor of Louisiana, and Permanent Parliamentary Secretary for Environment, Ottawa Canada. Dr. Ning is the Chair-elect of the Society of American Foresters Urban and Community Forestry Working Group, and Board member of the 7th American Forest Congress Communities Committee.

Dr. R. Eugene Turner is the Distinguished Professor in Louisiana Environmental Studies, Coastal Ecology Institute, Louisiana State University. He is sometimes an oceanographer

and at other times a wetland ecologist. He serves as Chair of the International Association for Ecologists (INTECOL) Wetlands Working Group, and as Treasurer of INTECOL. He was the recipient of the 1998 National Wetland Award, and along with Nancy Rabalais, of the 1999 Blasker Award for Science and Engineering for their work on the low oxygen zone off the Mississippi River (the DEAD ZONE).

Dr. Thomas W. Doyle is a research ecologist with the U.S. Geological Survey National Wetlands Research Center in Lafayette, Louisiana. He received his M.S. and Ph.D. in systems ecology and environmental science from the University of Tennessee in Knoxville. He has more than 20 years of field and modeling experience in temperate and tropical forest ecosystems of southeastern U.S. and the Caribbean. His research disciplines focus on wetland ecosystem analysis and modeling, forest stand and landscape simulation, tree-ring analysis, plant competition and growth modeling, and disturbance ecology. His tree-ring studies of southeastern coastal plain forests have produced growth chronologies of tree and species responses to climate, flood, fire, wastewater application, atmospheric CO₂, hurricanes, and land-use change. Growth models by species groups have been used in individual-based forest models to predict historic and future effects of climate change, altered freshwater flow, sea-level rise, hurricanes, and water quality issues. Landscape simulation models have been developed and integrated with stand-level models for various parks and refuges across the Southeast to forecast potential threats of habitat loss or conversion by natural and man-induced disturbances and climate change in mangrove, pine flatwood, and bottomland hardwood ecosystems.

Dr. Kamran K. Abdollahi is a Professor of Urban Forestry, Division of Agricultural Sciences, College of Agricultural, Family and Consumer Sciences at Southern University, Baton Rouge, Louisiana. Dr. Abdollahi was instrumental in establishing the first Urban Forestry B.S. degree granting program in the nation. His research expertise is in tree physiology, forest ecophysiology, phyto-remediation, and global change. Currently he directs 8 research projects emphasizing on quantification of tree species in removing pollutants from urban atmosphere and GIS-based ecosystem analysis. Dr. Abdollahi is the Co-Director of the Gulf Coast Regional Climate Change Assessment Program and the co-author of five books on climate change assessment. He was selected by the US Secretary of Agriculture to serve on National Urban and Community Forestry Advisory Council. He served as the Chair of the Society of American Foresters Urban and Community Forestry Working Group, and the State Director and Regional Board member for the International Society of Arboriculture. He serves on the executive board of the National Associations of State Colleges and Universities (NASULGC), Ecology Section. Dr. Abdollahi is the recipient of the Faculty Award for Excellence for Teaching Research Performance at Southern University College of Agricultural, Family and Consumer Sciences in 1998-2000, 1999 and 2003 University Research Grantsmanship Award, 1998 Louisiana Arborists Association Award, and 1994 Honors College Exemplary Faculty Award.

Dr. Enrique Reyes is an Assistant Professor at the Department of Geology and Geophysics, University of New Orleans in New Orleans, LA. His research focuses on development of ecosystem models, landscape ecology, approaches to coastal resource management using systems ecology, and analysis of ecosystem dynamics and processes in wetlands and tropical watersheds. His academic experience lies on "big picture" approaches to ecosystem analysis. Using simulation modeling as a research tool, his interests have been to understand how coastal areas respond to diverse impacts, natural and man made. Dr. Reyes has been active in several modeling efforts that span from plant productivity, fish migration, mesocosm experiments, to landscape simulation. Current project sites include the coast of Louisiana, the Everglades in Florida, and several coastal lagoons in the Mexican Caribbean.

Dr. Dubravko Justic is an Associate Professor at the Coastal Ecology Institute and in the Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA. Over the past fifteen years Dr. Justic has worked extensively on problems dealing with eutrophication, hypoxia, and impacts of climate change on coastal ecosystems.

Mr. Erick M. Swenson is a Research Associate in the Coastal Ecology Institute, a research unit within the School of the Coast and Environment at Louisiana State University in Baton Rouge, Louisiana. His research has focused on the investigation of human impacts on the hydrologic regime of coastal marsh systems. His research interests include measurement and analysis of velocity, sea level and salinity measurements in shallow-water, coastal, and estuarine systems. Mr. Swenson has worked on the analysis of long term historical data sets (water level, salinity, and climate) from Louisiana coastal ecological systems with emphasis on wetland restoration and management. Mr. Swenson serves as an Academic Advisor to the Environmental Working Group for the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA).

Dr. Wael M. Khairy is an Assistant Professor in the Center for Hydrology, Soil Climatology, and Remote Sensing, Alabama A&M University, Normal, AL. His research areas and specialties are watershed modeling for environmental applications, remote sensing and GIS applications using large-scale hydrologic modeling tools, climate change consequences on environmental quality, modeling of water quality in rivers and lakes, stochastic hydrology, environmental geostatistics, non-point source load pollution estimation, total maximum daily loads assessment, studying the impacts of drought conditions on water resource availability, and analyzing alternative water management scenarios to compensate water shortage.

Dr. Kam-biu Liu is the James J. Parsons Professor of Geography at Louisiana State University. He is widely recognized as a pioneer and leader in a new field of science called paleotempestology, which studies past hurricane activity by means of geological proxy techniques and historical documentary evidence. Since 1989, Liu has conducted extensive research on the sedimentary records of lakes and marshes along the Gulf of Mexico coast and Atlantic coast of the U.S. to study the chronological and spatial patterns of catastrophic hurricane strikes during the last 5,000 years. His broader research interests include the use of pollen and ice cores to reconstruct the history of climatic and vegetational changes in the Amazon Basin, Tibetan Plateau, Yangtze River valley, and the Canadian boreal forest. His research has been featured in national and international mass media such as the New York Times, Science Magazine, The New Scientists, Science News, Fortune Magazine, The Economist, CNN, BBC, and the Discovery Channel.

Dr. Alma Thornton is the Director of the Center for Social Research and Professor of Sociology at Southern University and A & M College. Her research has focused on psychosocial factors in health and nutrition disparity in the lower Mississippi Delta region. Other research interests include community development and revitalization that is comprehensive, locally based, centered on citizen participation, and involving public-private partnerships, and collaborations. She specialized in comprehensive planning and assessment, community building, capacity building, program evaluation, logic-based modeling, theory based models of change, and measurement and analysis. In addition, she works closely with non-profit, and faith-based organizations as community developer assisting in building and implementing programs.

5.2.2. Collaborative Partners

Gulf States institutions

To promote regional participation, we collaborated with the Gulf Coast institutions, includ-

ing Louisiana State University (LSU), Coastal Ecosystem Institute (CEI), Southern Regional Climate Center (SRCC), USGS National Wetland Research Center (NWRC); Alabama A&M University, Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS); National Institute for Global Environmental Change, Tulane University, and Tulane University Museum of Natural History; Florida State University; Global Hydrology and Climate Center, NASA/UAH/USRA; Urban Studies and Public Policy Institute, Dillard University; and Jackson State University.

Stakeholders

Outreach and stakeholder involvement was one of the fundamental components of the assessment. We expanded the stakeholder network that was initially established by SU through the Gulf Coast Regional Climate Change Assessment Workshop. The stakeholders included policy makers, managers, planners, scientists, private business owners, farmers, fishermen, minorities, and representatives of low-income communities.

National Assessment Teams

The Gulf Coast regional assessment team was actively involved in the National Assessment (NA) from the early stages. The regional leaders and assessment team representatives attended the NA forum and assessment related meeting/workshops. The team provided input to the National Assessment Synthesis Team (NAST) for the synthesis of the first NA report.

The United State Environmental Protection Agency (USEPA)

The USEPA was the sponsor for the regional assessment. Dr. Michael Slimak, Associate Director, National Center for Environment Assessment, was a Steering Committee member and was instrumental in planning and implementing the regional workshop, post-workshop activities, and further assessment activities. Dr. Joel Scheraga is a nationally known expert in climate change assessment and provided valuable input to the regional team. Dr. Susan Herrod-Julius, Project Officer, worked closely with the regional team. Her scientific background and expertise in climate change assessment were of great importance to the regional team.

5.3. Communication, Outreach, and Education Efforts

5.3.1 First Phase (Regional Workshop) Communication, Outreach, and Education Efforts

To ensure the proper dissemination of the workshop findings and recommendations, we have

- (1) Conducted a follow-up symposium on global climate change,
- (2) Participated in a regional radio talk show on climate change,
- (3) Given presentations at the Global Warming 9th International Conference, EPA region 6 Non-point Source Pollution Conference, and SU Chancellor's Media Breakfast,
- (4) Made presentations to the region's congressional staff and to the National Conference of Black Mayors,

- (5) Hosted a community future forum on land use change,
- (6) Presented lectures to college and high school students on the climate change issue,
- (7) Made a presentation at the HBCUs' Environmental Technology Consortium, and
- (8) Given a presentation at the Society of American Foresters National Convention.
- (9) A Summer Institute on climate change, forests, and urban forests was held for regional school teachers and counselors in collaboration with the Baton Rouge Green.
- (10) A public forum was also organized to give regional people an opportunity for discussions and for team members to present research result. This forum was designed to seek dialog, and to discuss the impacts of climate change on the regional commerce, culture, and quality of life.

5.3.2 Second Phase (Further Assessment) Communication, Outreach, and Education Efforts

Communication, outreach, and education were some of the key elements of the further assessment. Some of the highlights were:

Briefings to educational groups and visiting scientists that explained the climate change research and assessment activities;

University wide presentations on global climate change and the wetlands in Louisiana;

An outreach activity on climate change and its impacts on minority and small business at the "New Realities in Business Workshop" hosted by a partnership of federal agencies and minority serving institutions, and minority businesses;

Upon the request of the US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), provided assessment results to NOAA;

Outreach to high school teachers and students through SU GLOBE STS (Spinning toward Solutions) Program hosted by NASA and Southern University;

Organized technical session at the Society of American Foresters 2000 National Convention in Washington, D.C.;

Organized Earth Day symposium with global climate change as a theme;

Enhanced the capacity of Southern University in climate change education and research,

Development and implementation of the first graduate level course on "Global Change and Environmental Consequences", approved by the LA Board of Higher Education,

Integration of climate change educational material into the undergraduate courses at Southern University;

Developed of a web site for assessment activities;

Increased research opportunities for SU and LSU faculty and other regional universities;

Developed a graduate thesis on climate change and human dimension;

Developed a poster gallery on climate change assessment;

Contributed educational material to libraries in the nation and overseas; and

Presented the assessment results at conferences, meetings, and seminars.

5.3.3 Media Coverage

The regional assessment activities captured the attention of major media outlets. The regional media provided in depth coverage of the regional assessment. There were news articles, feature articles, TV news reports, and radio spots throughout the assessment process. The lists below displays some of the examples.

Southern Picked to Host Regional Forum on Global Warming The Advocate (Capital City News Paper), Baton Rouge, LA, pp 4A, Tuesday, December 2, 1997;

Southern Picked to Host Regional Forum on Global Warming National Public Radio (NPR), Tuesday, December 2, 1997;

Southern University Will Host a Global Climate Change Conference WBRZ (ABC Affiliation), 10pm News Top Story, December 9, 1997;

Global Climate Change Conference in BR to Look at Gulf Coast's Future The Advocate, Baton Rouge, LA, pp. 17A, Tuesday, February 24, 1998;

Southern University Will Host a Climate Change Public Forum WBRZ Channel 2, February 26, 1998;

Community Calendar: Climate Change Public Forum Hosted by Southern University The Advocate, February 26, 1998

Gulf Coast Regional Climate Change Workshop WBRZ, Channel 2 (ABC affiliate) 10:00 p.m. News Top Story. Thursday, February 26, 1998.

Advisor Says Halt Warming, Not Economy The Advocate, Baton Rouge, LA, pp.2B, Friday, February 27, 1998;

Storms Dumping on State, Experts Claim, LA Getting Wetter, Not Warmer The Time Picayne, New Orleans New Paper, New Orleans, Friday, February 27, 1998;

LA May Face Increase In Diseases Saturday Advocate, Baton Rouge, LA, pp 11A, Saturday, February 28, 1998.

What a Fantastic Conference Channel 9 (CBS affiliate), Evening News, Saturday, February 28, 1998;

El Nino Brings Wet Weather; La Nina Worse Sunday Advocate, Baton Rouge, LA, pp 1-2B, Sunday, March 1, 1998;

Scientists Gather in Baton Rouge to Share Knowledge about Gulf Coast Climate Changes LSU Agricultural Center News, March 5, 1998;

1998 El Nino, One of Many That Occur Every Few Years LSU Agricultural Center News Radio, March 5, 1998;

LA Affected by El Nino in Different Ways LSU Agricultural Center News Radio, March 5, 1998;

Southeast U. S. Agriculture Producers Can Prepare to Take Advantage of El Nino LSU Agricultural Center News Radio, March 5, 1998;

Hurricane Threats, Coastal Complacency Studied The Advocate, Aug. 18, 1999

Aug. Unusually Hot, Records Show The Advocate, Aug. 18, 1999

Research for the Environment and Community Sunday Advocate Science & Technology Aug. 1, 1999

Report Sees Drier, Smaller LA by 2100 The Advocate, June 13, 2000

SU Faculty Receives Grant for Climate Research SU Insider, July 2000

SU Faculty Writes First Book on Climate Change in Gulf Coast Area The Southern Digest News Services, Feb. 4, 2000

Climatic Impact Sunday Advocate Science & Technology, March 5, 2000

Experts unearth a Stormy Past The New York Times Science Times section, July 24, 2001.

Coral-Killing Cyclones Science Now, October 3, 2001, the online science magazine published by the American Association for the Advancement of Science (AAAS).

Climate Change's Effects Documented, Long-term Impact on Gulf States Studied The Advocate Oct. 22, 2001. Special Issue on Climate Change.

Media Moments The Forestry Source Dec. 2001 Vol. 6, No 12

El Nino a Time to Hold Breath – Flood Potential Rises as Pacific Warms The Advocate, February 20, 2002

5.4 Lessons Learned in the Regional and National Assessment of the Potential Consequences of Climate Change

Key elements to a successful assessment process

The US national climate change assessment process has been very successful and has set a fine example for other countries that are comparable to the US in geographic size, population, and economic development. The key elements to a successful assessment process, based on lessons learned over the past few years of the regional assessment, are:

- clear guidelines,
- adequate funds,
- collaborative efforts,
- overall coordination,
- broad participation,
- strong support from government, scientific communities, and stakeholders,
- media attention and support, and
- variety of publications for all types of audiences.

The accomplishment of the assessment objectives and means to measure the success

The initial objectives for the Gulf Coast region were to assess potential consequences of climate change for the region, specifically wetlands, forests, water and air quality, energy and commerce, recreation and community life. These objectives were reached during the first phase of the assessment (1997-1998). Due to time constraint and limited funding for the second phase (2000-2002), the assessment was narrowed down to two sectors, coastal ecosystems and forests. Publications such as books, journal articles, proceeding papers, and news articles, were used as measures of success. Also, education and outreach efforts such as presentations, distribution of publications, symposia, seminars, summer institutes, roundtables, and meetings, were also used as measures.

Stakeholder process

The regional stakeholders included community representatives, private business owners, local, state, and federal employees, and policy makers. Minorities including African Americans, Hispanics, Asians, and Native Americans were well represented. Stakeholders from diverse backgrounds were attracted to and became involved in the assessment process because the assessment team contacted community leaders, minority leaders, visited local communities, talked to various community based associations, presented seminars and lectures at universities and schools, and sent invitations for group discussions. We informed the stakeholders by briefing them on the current status of the science of climate change and stressed the potential impacts to their environment and quality of life. We also incorporated their knowledge through organizing discussions on topics of their interests and soliciting white papers reflecting their expertise. We maintained stakeholder involvement throughout the entire assessment process by suggesting that they visit and provide comments on the website, by inviting them to serve as reviewers, and by inviting them for follow up workshops and meetings.

Assessment topics selection

The Gulf Coast regional assessment started with a well-organized regional workshop with participants from both the scientific communities and stakeholder communities. The scientists including regional climatologists, ecologists, modelers, health experts, and plant physiologists among others, provided stakeholders with general information on climate change and its potential impacts. Stakeholders were then asked to identify current issues and problems associated with climate change, as well as identify information and research needed for the assessment. Based on the stakeholders' input, the assessment addressed issues of coastal ecosystems and maritime forests.

Assessment communication

Stakeholders were aware of some general issues such as greenhouse effects, raising temperature, sea-level rise, wetland loss, etc., at the beginning of the assessment process. The regional communication efforts enabled the stakeholders to broaden their knowledge about key issues and potential impacts, such as health threats, ecosystem unbalance, agricultural issues, flooding, drought, water and air quality, extreme weather events, and forest. The assessment message was disseminated throughout the Gulf States. The assessment has promoted a regional interests in climate change and drawn more participation by regional people. As the assessment proceeded, it was noticed that more stakeholders sent emails and letters requesting reading materials, journalists requested interviews, topics were chosen by students as research projects, and scientific groups requested participation in report writing.

We found that newspapers are the most effective media for outreach to the public because they are read by a large general public audience. Mid-size reports written in popular scientific language could reach larger audiences than could large, conventional reports. Our webpage effectively disseminates information.

Assessment and its effects on decision making

Assessment information was used by the Louisiana Governor's Office for Coastal Activities for their report for the state legislature. Assessment publications were used as class reference books and articles at the university level. Also, assessment publications were used for compiling climate change related reports by other groups. For example, the Union of Concerned Scientists (UCS) used the Gulf Coast assessment finding in its report and for the Louisiana scientists statement on climate change to the United States Congress.

As a result of the assessment and related activities by many parties, there is a higher degree of public awareness about the impacts of accelerated sea-level rise in the state of Louisiana. In February of 2001, the Louisiana Wildlife Federation (which is an alliance of about 35 hunting, fishing and conservation groups in the state) passed a resolution urging the state and federal agencies to consider accelerated sea-level rise in their coastal management and protection plans for the state. Below is an excerpt from this resolution:

"Therefore be it resolved, the Louisiana Wildlife Federation calls for increased protection for existing coastal wetlands and increased scrutiny of dredge-and-fill permits by state and federal regulatory agencies.

Be it further resolved, the Louisiana Wildlife Federation urges and requests that sea-level rise be considered and formally integrated into restoration, management and regulatory programs of the Louisiana Coastal Zone Management Program.

Be it also further resolved, the Louisiana Wildlife Federation urges and requests the Louisiana Department of Natural Resources to adopt policies and regulations to establish setback lines for coastal development that will allow for the natural migration of wetlands, barrier islands and other coastal habitats as sea-level rises."

Long-range socio-economic development and planning for the Gulf Coast must be based on realistic assessments of the risks posed by intense hurricane strikes and, perhaps to a somewhat lesser extent, catastrophic wildfires. Until recently there was no empirical means by which both hurricane and fire risks can be estimated, because long-term records (i.e., those spanning more than one or two centuries) of these hazards were lacking. Team conducted a case study on "Assessing the Vulnerability of the Alabama Gulf Coast to Intense Hurricane Strikes and Forest Fires in the Light of Long-term Climatic Changes." In this case study, we have presented a 1200-year record of intense hurricane strikes and wildfires for the Alabama Gulf Coast based on a stratigraphic study of overwash deposits, charcoal, and microfossils in a core taken from Little Lake. The work on paleotempestology was recognized in the Science Times section of the New York Times on July 24, 2001. This article was widely read by the public as well as policy makers. This article promotes the importance of integrating a long-term perspective into the societal response to hurricane and forest fire hazards.

Stakeholder involvement and the assessment process identified future research agendas. This ensures that the results from future research will be useful to the stakeholders and the society. The assessment process helped the region to realize what is known, what is unknown, and what is needed to illuminate the unknown.

The Gulf Coast regional assessment results have been reported in regional news papers and TV news, quoted in environmental awareness programs, used as reference material in

global change and environmental science related classes, and was used by NAST for the National Assessment synthesis report. Copies of the Gulf Coast assessment publications were requested by NOAA, and according to NOAA administrator, James Baker, the agency “will use the information for variety of purposes.”

Agency support

The USEPA provided guidance for the assessment process along with the USGCRP. Dr. Michael Slimak, Associate Director for Ecology, at the USEPA National Center for Environmental Assessment was instrumental in establishing the Gulf Coast region as one of the 19 regions included in the National Assessment and providing the workshop support. The EPA Global Change Program Director Dr. Joel Scheraga and the Project Officer for the Gulf Coast region Dr. Susan Herrod-Julius were easily accessible. They conducted site visits and participated in the assessment team’s meetings. It is noteworthy to mention that the Program Director and the Project Officer responded to phone calls and emails promptly and provided solutions to problems related to the assessment.

The USGCRP through its Director of the National Assessment Coordination Office and the Regional Liaison, provided leadership and directions for the regional and national assessments. The USGCRP and the NACO Director’s attention to underserved communities was important for the full participation of people of all ethnic backgrounds in the assessment process.

Regional efforts – key to a successful assessment

The consensus is that regional teams are essential for the continuation of future regional assessment on global change. Each region has its unique problems and impacts. Regional scopes and assessment results are more useful to regional policy makers, scientists, and stakeholders than national assessments alone. A multi-issue approach that includes a wide range of concerns such as land use change, energy, etc., is necessary to encourage people from different ethnic backgrounds to participate. A multicultural approach represents broader areas and more communities, and provides an efficient means of reaching out to these communities.

International collaborations

The Gulf Coast region has collaborated with China through the Chinese Academy of Sciences. The Chinese scientists are very interested in conducting their assessment across regions and sectors. They are very impressed by the US assessment methods and process and have established some collaboration with US in some sectors and regions. The Gulf Coast region also established collaborative efforts with scientists in Italy, Canada, and Jamaica. The Italian scientists organized special seminars and lectures in three universities/institutes for the Gulf Coast region team members. The Canadian counterpart participated in the regional workshop. Team members provided technical assistance to the Jamaican Ministry of Agriculture and Forestry Department on management and conservation of the national forests in a changing climate.

5.5 Peer Review Process

The Gulf Coast regional climate change impact assessment findings were compiled based on the regional assessment research, outreach, and education results. Prior to the publishing, a three level technical peer review and stakeholder review was conducted.

First level:

We conducted a technical peer review by scientists/peers/technical experts for scientific and technical accuracy and validity. A minimum of 2 reviewers reviewed each chapter corresponding to the expertise required to review each chapter. All reviewers were from outside of the assessment team and Southern University. The review process were coordinated by the Assessment Team Leader/Project Director Dr. Zhu H. Ning, who provided a central distribution and receiving point for written review and oral review comments. The team members were responsible for documenting the responses to review comments of the respective chapter.

Second level:

We identified the stakeholder groups and individuals for their review, including all of the groups that participated the regional first stakeholder workshop in 1998. We also sent the manuscripts to many stakeholder groups we have contacted, met with, and/or presented information to since the inception of the assessment. We provided adequate time for a general comment period by the stakeholders.

Third level:

After the first two levels of review were accomplished and all comments and responses were documented, we conducted an overall peer review for the technical and editorial responsiveness. For the overall peer review, we had a batch of reviewers who have broad expertise and reviewed all of the chapters and any summaries, conclusions and connections that were made in the document that cut across the chapters. All documentations of response to reviewers' comments are available and can be obtained by contacting Dr. Zhu Hua Ning at zning@subr.edu, or (225) 771-2262 ext. 267 (phone), or (225) 771-3286 (fax).