Gulf Coastal Forests in a Changing Climate

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ABSTRACT. Changes in forest composition and distribution will alter the value and function of maritime forests in ways that may impact the regional economy of Gulf States. These forest systems provide critical services for wildlife, forestry, recreation, ecotourism, fisheries, and shoreline protection that will be at risk under climate change. This paper focuses on the potential consequences and challenges of climate change that are posed on maritime forests of the Gulf Coast region. We conducted and 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.

Introduction: Current Status and Stresses of Gulf Coast Maritime Forests

Coastal environments are among more biologically diverse and productive compared to upland systems. 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 service 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 affected 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.

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 (15,000B.P.) and over the last century by as much as 1-2 mm/year. The latest Intergovernmental Panel on Climate Change (2007) 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, which can affect 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.

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 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.

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).

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.

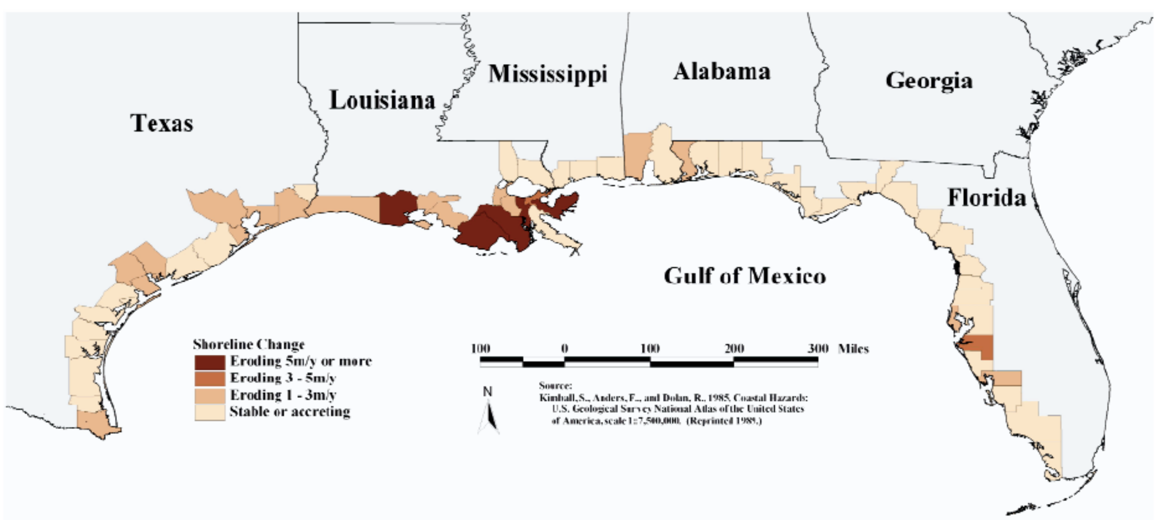


Figure 1. Coastal erosion rates for all coastal counties and states for the Gulf of Mexico region modified after Kimball *et al.*(1985).

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 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.

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 bottomland hardwood systems. Saltwater intrusion into maritime

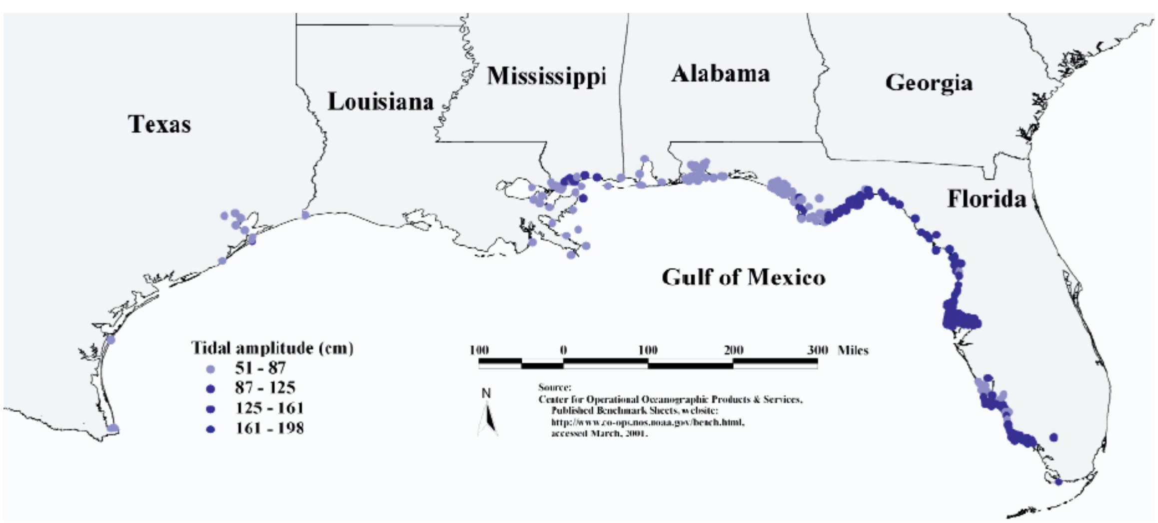


Figure 2. Tidal range (MHHW-MLLW) for NOAA tide stations along the Gulf Coast of Texas, Louisiana, Mississippi, Alabama, and Florida.

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.

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 leaflitter 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.

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.

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 SELVAMANGRO 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.

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 GISbased 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.

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.

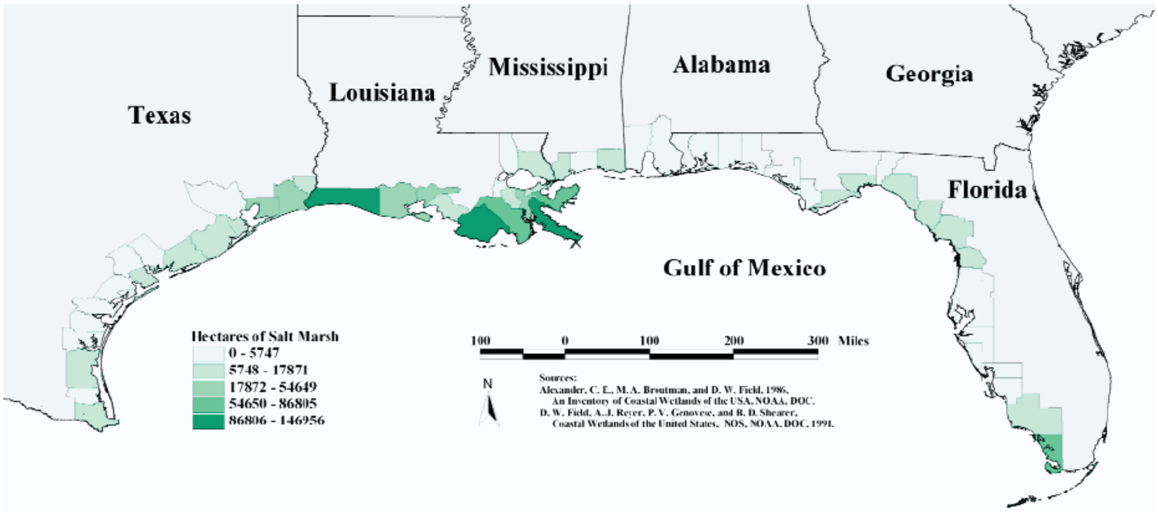
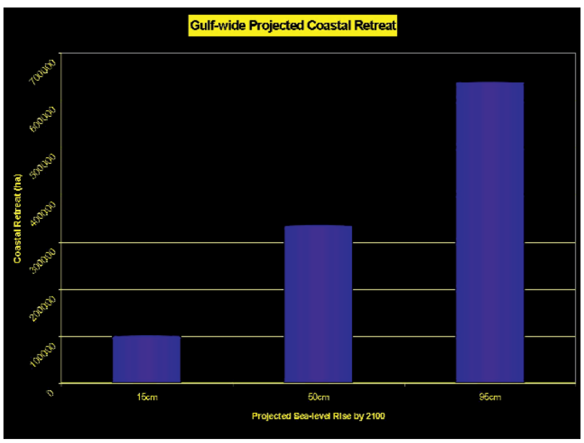


Figure 3. Saltmarsh area (ha) for each county and state along the Gulf of Mexico based on National Wetlands Inventory sources compiled by Field et al. 1991.



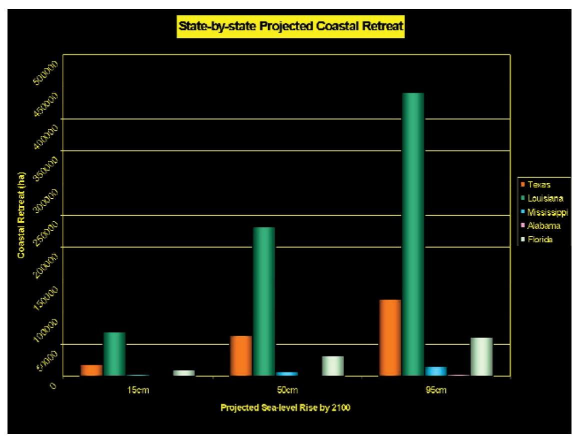


Figure 4. Projected losses (ha) of maritime forest by coastal retreat for the entire Gulf Coast for a low, mid, and high estimate of eustatic sea-level rise by the year 2100.

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.

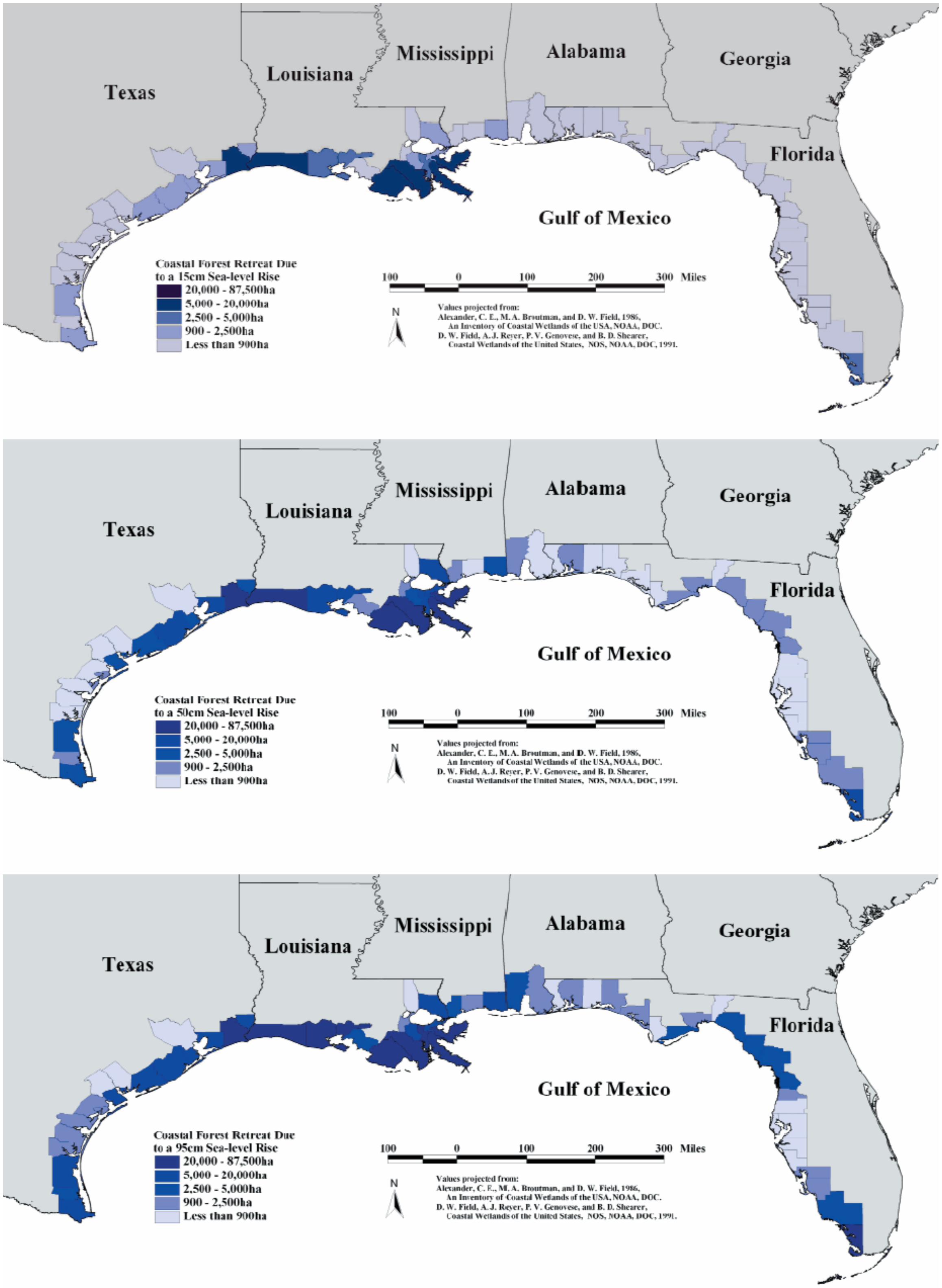


Figure 6. Predicted coastal forest retreat based on GULFWIDE simulation model for all counties and states along the Gulf Coast for climate change scenarios of 15, 50, and 95 cm rise in sea level by year 2100.

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 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 production 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 desalinization plants and other conservation measures.

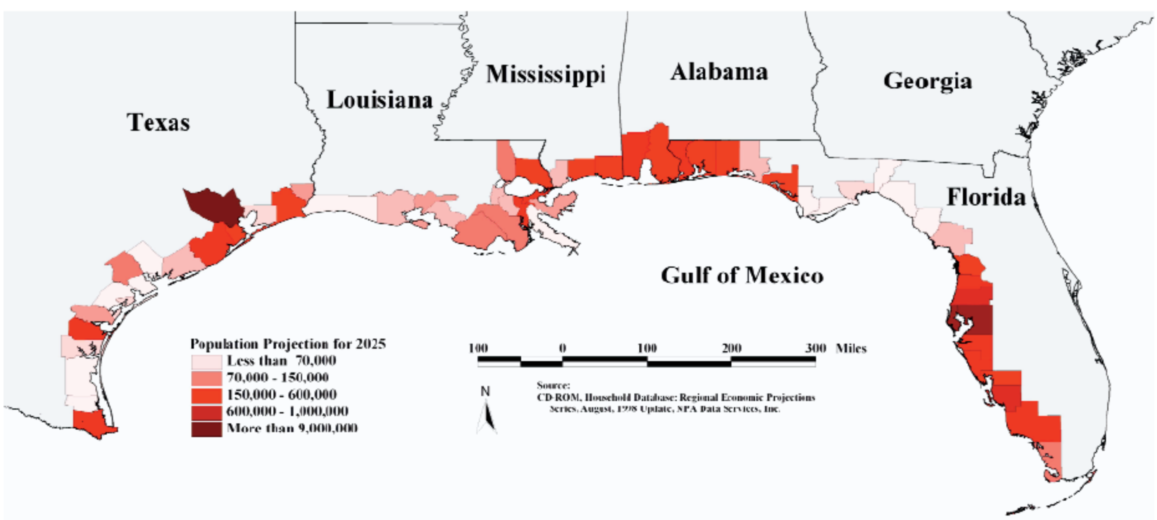


Figure 7. Projected human population estimates for Gulf Coast counties and states by the year 2025.

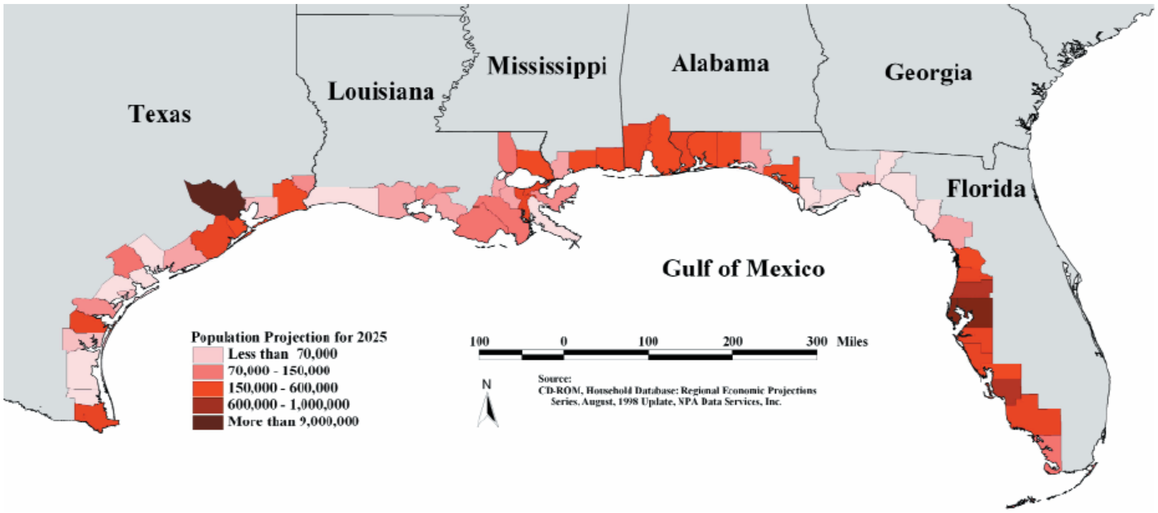


Figure 8. Projected population growth rate by county and state for the Gulf Coast region.

Challenges and Opportunities

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 responsiblity. 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 exaccerbate 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.