Chapter 1:
Overview of Coastal Wetland Global Climate Change Research

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The potential impacts of climate change are of great practical concern to those interested in wetland resources. In particular, land managers need a better understanding about the potential environmental consequences of climatically induced changes and how management practices may influence or preserve critical habitat and mitigate potential ecosystem change. The U.S. Global Change Research Program (USGCRP) was undertaken to provide a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changing climate. Among the areas of greatest risk in the United States are low-lying coastal habitats and ecosystems along the northern Gulf of Mexico and southeast Atlantic coasts. These areas are vulnerable to the effects of climate-related change because of their elevation relative to sea level, low relief, and exposure to a host of human-induced stresses.

The Intergovernmental Panel on Climate Change (IPCC) has developed a range of scenarios for future greenhouse gas and aerosol precursor emissions which, when coupled with "best estimate" values of climate sensitivity and ice melt sensitivity to warming, project an increase in mean global sea level ranging from 15-95 cm by the year 2100 with a projected global mean mid-range increase of 50 cm (Intergovernmental Panel on Climate Change 1995b). That increase will result in widespread inundation of coastal areas, loss of coastal wetlands, and loss of many economic support functions those ecosystems provide. Indeed, sea-level rise that has occurred since 1940 has already inundated areas of the southeastern U.S. coastal zone. A projected additional 30% loss of coastal wetlands with a 50 cm increase in sea-level is of tremendous economic and biological importance (OTA 1993). Coastal wetlands provide essential habitat for many endangered and threatened species as well as supporting an economically important sports fisheries. The coastal areas of Louisiana alone provide the natural resource base for a fish and shellfish industry of over $1-billion-per-year.

Partners

As part of the USGCRP research framework on coastal lands and ecosystems, the Biological Resources Division of the U.S. Geological Survey (National Wetlands Research Center) entered into partnership with Rice University, Louisiana State University, Duke University, Clemson University, University of Southwestern Louisiana, University of Georgia, and the Virginia Institute of Marine Science (College of William and Mary) to:

(1) document the current state and vulnerability of coastal ecosystems including an assessment of past changes in land cover, (2) develop an understanding of the processes which underlie these changes, and (3) predict the extent of future alterations to these habitats and the consequences for the sustainability of the resource and land base.

This document summarizes the initial findings of our collaborative efforts. Overall, the studies exemplify an integrated approach addressing questions at the species, community, and landscape levels of organization and focusing on factors related to hydroperiod, sea-level rise, disturbance events, and coastal marsh submergence.

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Climate Change and Threatened Coastal Habitats

Coastal wetlands are particularly vulnerable to the effects of global climate change. Located on the interface between land and water, wetlands will be affected by large-scale climatic shifts. For example, subsidence (the rate at which land is sinking with respect to sea level) and sea-level rise (caused by thermal expansion of oceans and melting of polar ice caps and glaciers) are currently not being balanced by accretion (sediment accumulation) in many wetlands along the northern Gulf of Mexico Coast, resulting in increased flooding, saltwater intrusion into freshwater wetlands, and erosion of the coastline. Through natural processes, many coastal wetlands maintained their relative elevation to gradual increases of 1-2 mm per year in sea-level rise over the last several hundred years, but these rates are projected to increase twofold to threefold during the next century (Intergovernmental Panel on Climate Change 1995b).

Global change models for the southeastern United States predict a change in the temperature regime but no reliable changes in precipitation patterns (Giorgi et al. 1994). Regional models have predicted a 3 to 4° C increase in temperature region wide; however, all coupled ocean-atmospheric models used in the IPCC's Second Assessment Report predict an increase in precipitation over mid to high latitude regions as a result of a warmer climate. Variations in patterns of precipitation and temperature can affect the growth of individual trees, tree species population dynamics, ecosystem structure, and the geographic distribution of low lying forests and forest communities lying at the interface between terrestrial and aquatic systems.

Underlying the predicted climatic change is an overall increase in carbon dioxide concentrations in the atmosphere. The current evidence suggests that high concentrations of atmospheric carbon dioxide will affect atmospheric and oceanic processes that will have an impact on coastal wetlands (Edgerton 1991). Curtis et al. (1989) showed that salt marsh communities directly respond to increased atmospheric carbon dioxide with increases in biomass production. Although these increases may appear to be positive effects, the long-term response of vegetation to elevated carbon dioxide levels is still uncertain. Translating the responses at the cellular and leaf level in controlled experiments to community and ecosystem responses is difficult (Solomon and Shugart 1993). Increased atmospheric carbon dioxide concentrations should also result in a linearly proportional increase in dissolved carbon in coastal waters, which may potentially affect the biology and ecology of submersed plant communities.

Global climate models also include predictions about the nature of tropical storms (Emanuel 1987; Knutson et al. 1998). The coastal zones of the Gulf of Mexico and parts of the southern Atlantic Ocean are particularly vulnerable to hurricanes as evidenced from historical patterns of storm tracks and the consequences of recent storms (Guntenspergen and Vairin 1996; Michener et al. 1997). Freshwater marshes are susceptible to pulses of salt water during storms. Coastal forests are susceptible to direct damage from wind and storm surge sufficient to alter forest structure and diversity. Animal communities are locally susceptible to high winds and flooding associated with storms. And coastlines are susceptible to geomorphic changes and erosion. Although the IPCC (1995) concluded that the science is currently inadequate to state whether or not tropical storm frequencies or intensities will increase, some global climate change models predict changes in the frequency and intensity of tropical storms (Emanuel 1987).

The coastal zone of the southeastern United States consists of a matrix of open water, different wetland types, and upland. This matrix provides habitat for distinct groups of wildlife. Each of these habitat types requires an improved understanding if we are to predict and plan for changes caused by climate-induced environmental alteration.

Submersed aquatic vegetation (SAV), both freshwater communities and seagrasses, provide food for wintering diving ducks and habitat for fish. These communities are quite sensitive to changes in their physical environment. Scenarios for future climate change would affect the location, extent, composition, and productivity of these communities. Coastal emergent marshes provide habitat for a different array of waterfowl and terrestrial wildlife as well as serving as a vital nursery habitat for fish and shellfish. These habitats are particularly vulnerable to the effects of submergence, saltwater intrusion, and tropical storm activity. Forested wetlands and upland forested systems provide important habitat for colonial nesting birds, raptors, wintering and resident waterfowl, deer and other mammals, and Neotropical migrants. Lowland forests are sensitive to altered hydrology, salinity, and tropical storms.

Scientific assessments of current resource condition, an understanding of the large-scale processes operating in these systems, and an ability to predict the vulnerability and adaptability of natural and managed systems to the consequences of the long-term variations of the physical environment have long been needed. The research described in this document provides some understanding of climate change impacts on U.S. coastal wetlands.

Goals

The wetland global change research program in the U.S. Geological Survey was organized in a hierarchical framework to: (1) identify sensitive ecosystems and critical processes, (2) understand their current condition, (3) develop new tools and technology to identify sensitive systems and measure critical processes, (4) develop predictive tools which model the vulnerability of habitats to environmental changes, and (5) develop management recommendations to ameliorate the potential environmental impacts associated with global climate change. Research in the Gulf of Mexico and South Atlantic Coastal Plain has concentrated on land managed by the Department of the Interior's U.S. Fish and Wildlife Service's (USFWS) National Wildlife Refuge System and by the National Park Service (NPS). In this region, the USFWS manages 65 national wildlife refuges, and NPS manages 27 national parks. Climate change is projected to have significant regional impacts on resource management and use of these public lands. Southeastern coastal wetlands have also been high priority areas for state fish and wildlife agencies because of the renewable resource base associated with these unique and vulnerable habitats.

Submersed Aquatic Plant Communities

Communities of submersed aquatic vegetation (SAV) found in marine, estuarine, and freshwater environments within the northern Gulf of Mexico coastal zone provide critical habitat for fish, shrimp, wintering waterfowl, and endangered species including sea turtles and manatees; reduce erosion; and improve water quality.

Field and laboratory experiments conducted by USGS scientists addressed the possible impact of elevated dissolved inorganic carbon, sea-level rise and salinity increases, and increased physical disturbance by storms on the ecology and function of submersed aquatic plant communities. Studies on the effects of elevated dissolved organic carbon examined the photosynthetic response of phytoplanktonic, benthic microalgae, and macrophyte components of these habitats as a potential measure of shifts in the organization and structure of the submersed aquatic plant community. Increased atmospheric carbon dioxide is likely to lead to increased concentrations of dissolved carbon and thus lead to widespread changes in the productivity of these communities, changes in the food quality of these species for fish and wildlife, changes in the growth patterns of the plant species, changes in species composition, and possible extirpation of SAV by competition with phytoplankton and epiphytes.

Greenhouse experiments with wild celery (*Vallisneria americana*) and shoalgrass (*Halodule wrightii*) exposed to increased levels of dissolved inorganic carbon resulted in changes in biomass allocation, ratio of carbon to nitrogen in certain tissues, and enhancement of epiphytic growth on the seagrass species. These experiments did not result in increased growth of the two species in the short-term, however.

Rates of photosynthesis increased in experimental treatments with three freshwater SAV species: wild celery, coontail (*Ceratophyllum demersum*), and hydrilla (*Hydrilla verticillata*) as well as shoalgrass exposed to higher concentrations of dissolved carbon dioxide. The results of experiments with shoalgrass are particularly significant because seagrass photosynthesis is often thought to not be limited by dissolved inorganic carbon concentrations because of the abundance of carbonate carbon in the water column. In these experiments, the lack of response by widgeon grass (*Ruppia maritima*), another species of submersed aquatic macrophyte, was likely a result of elevated levels of dissolved inorganic carbon as well as free carbon dioxide.

The distribution and abundance of submersed aquatic vegetation along salinity gradients has long been recognized for many coastal areas so we can associate general groups of species with broad salinity zones. Our understanding of the mechanisms underlying these patterns, however, is limited. Community composition at any location reflects the salinity tolerances of individual species as well as the biotic interactions among species. Although these salinity tolerances have been determined for many North American SAV species, there is little information on the relative importance of biotic interactions in structuring SAV communities, particularly under changing environmental conditions. Greenhouse studies assessed the salinity tolerance of six of the most common SAV species found in the coastal waters of the United States. They represented a range of habitat types (from freshwater to brackish). Additional experiments determined how potential distribution patterns might be altered by competitive interactions. Species known to be strong competitors dominated at low salinities and did not grow well at the high end of the salinity gradient because of a physiological intolerance to high salinity conditions. Species tolerant of high salinities proved to be weak competitors at low salinity. Species presence appears to result from an interaction between tolerance to the physiological stress associated with high salinity levels and the ability to compete and grow well in the presence of other plant species. Predictions for alterations in the salinity of any coastal area can be derived from physical information on local geomorphology, watershed freshwater inputs, volume of the tidal prism, and predicted sea-level rise. This information can then be used to predict changes in the SAV community structure.

An increase in the severity or frequency of tropical storms associated with global climate change could have acute impacts on coastal SAV communities. Studies which examined the role of chronic physical disturbance in patterns of seagrass distribution and abundance in coastal Louisiana were initiated so that predictions about the responses of coastal SAV to increases in storm disturbance could be made. These field studies indicated that seagrass community structure can be controlled by frequent and relatively minor overwash sediment deposition events. One seagrass species, turtlegrass (*Thalassia testudinum*), was found in protected areas characterized by nutrient-rich sediments of high organic content and low sand content.

Another dominant seagrass species, manatee grass (*Syringodium filiforme*), was found in patches characterized by sandy sediments. Increasing the deposition of sandy beach and offshore sediments in seagrass beds will result from a rise in the frequency of low intensity storms. The chronic effects of the predicted increases in sediment deposition from storm-generated waves is expected to cause a shift in community structure and species composition of these habitats to species commonly found after disturbance.

Coastal Marshes

The loss of coastal wetlands in the southeastern United States has accelerated in the face of relative sea-level rise during the past 50 years. Although many coastal wetlands have maintained their elevations relative to sea level in spite of a 1-2 mm per year rise in mean sea levels, local geomorphic processes complicated by human activities have led to the submergence of coastal wetlands and contributes to rates of coastal wetland loss in south Louisiana exceeding 65 km^2 per year. Areas in south Louisiana with high local rates of subsidence are currently experiencing relative sea-level rise rates up to 10 times the current global mean sea-level rise. U.S. Geological Survey scientists and their collaborators have sought to evaluate the potential for the submergence and subsequent loss of a range of saline and brackish marsh types relative to the local rate of sea-level rise.

Along the coast of the United States, marsh submergence can only be prevented if sediment accumulation and biogenic processes result in a vertical buildup of the marsh surface that keeps pace or exceeds the rate of relative sea-level rise. Surface elevation lagged behind sediment deposition at 7 of the 12 coastal wetlands monitored by USGS scientists. Four of the sites which exhibited significant loss of elevation relative to sea level had high rates of sediment accumulation, suggesting that subsurface processes in the top few meters of the soil as well as biogenic and external physical forces (storms) affected surface elevation. It is quite likely that estimates of marsh loss based only on tide gauge records and rates of sediment accumulation underestimate actual rates of subsidence. Predicting the potential for coastal marsh submergence caused by sea-level rise requires site-specific information and an improved understanding of the interactions among marsh vegetation, soil, and hydrologic processes. These initial findings cannot be extrapolated to all southeastern coastal wetlands. Information on local environmental factors, including coastal geomorphology, sediment supply, and frequency of major storms as well as trends in mean sea-level rise are needed to identify specific coastal wetlands at risk of submergence caused by global climate change.

Duke University and USGS scientists also found that as sea level rises and lower elevation sites are submersed and lost, marsh build-up and expansion can occur on the upslope landward marsh boundary, creating new wetland habitat and replacing lost marsh. The slope of the coastal plain as well as the rate of sea-level rise and sedimentation are key factors controlling the upslope movement of coastal wetlands. Horizontal migration can be impeded, however, if the slope of the surface is too steep or if barriers to new marsh formation exist upslope (e.g., sea walls, roads, or buildings).

Duke University and USGS scientists modeled the movement of the marsh edge in North Carolina's Pamlico Sound. Their results imply that the movement of the marsh edge occurs in a series of dynamic events rather than in a gradual constant manner. These "transgression" events are separated by longer periods of relatively little marsh edge movement. Upland movement of the marsh is associated with disturbance of the upland vegetation associated with major tropical storms or fire. The general model implies that upslope marsh movement is driven not only by sea-level rise but also by local environmental conditions. Marsh managers should not rely on short term estimates of upslope marsh movement as a tool which would predict coastal marshes at risk for submergence. To avoid a net loss of marsh habitat, they should employ management techniques, including the removal of upslope barriers, which would enhance marsh development upslope and minimize the potential for marsh submergence and net habitat loss.

Net Loss of Coastal Habitat

At St. Marks National Wildlife Refuge in northwest Florida, elevation and water depth are key factors controlling habitat type. The ability to predict landward transgression of coastal marsh caused by sea-level rise depends on knowledge of the current vegetation distribution and relation to topographic gradients. Field data were collected to establish correlations between vegetation distribution and surface elevation. These data were combined with the development of landscape models and new satellite technology to provide important tools for research and policy purposes that allow for effective land and water management, risk assessment, and cumulative impact analysis.

New satellite remote sensing techniques were developed to produce a fine scale resolution topographic map of the low lying coastal marsh. Color infrared photography, satellite imagery, and satellite radar images were combined to create additional maps of the marsh and upland vegetation of the refuge. A digital elevation model of St. Marks NWR was constructed to track the process and pattern of coastal inundation for given sea-level rise projections. Sea-level rise projections adopted from the IPCC (1995) indicate that major portions of the St. Marks coastal zone will be permanently flooded, bringing about a migration of vegetation community types and loss in total area and proportion of some habitats. Model results suggest that there is a large land base that will be quickly converted from coastal salt and freshwater marsh to open water, which will approach the scale of marsh loss that has been experienced in south Louisiana. There will be some shift of emergent marsh into forested zones. Site geomorphology and the slope of the land will present an effective barrier to the establishment and growth of specific plant communities because of lack of suitable habitat conditions. The landform in this area increases sharply in slope from the sea inland, effectively squeezing area available for forest and marsh.

Coastal Forested Wetlands

Forested wetlands at low elevations are among the coastal communities that are considered most vulnerable to losses due to potential changes in sea level. Many of these forests are already threatened by alterations in hydrology and saltwater intrusion. USGS scientists and their collaborators from Clemson University and the University of Georgia examined the effects of potential increases in flood durations and salinity levels through a series of growth and physiological experiments with 10 major wetland tree and shrub species.

Measures of plant physiological activity using experimentally simulated environmental conditions predicted to occur under different climate change scenarios were good predictors of whole plant growth responses that may not be evident for years or decades. Baldcypress (*Taxodium distichum*) was relatively tolerant to permanent flooding but relatively intolerant to exposure to saline waters. Oaks, which usually occur on ridges no more than 30-60 cm above the surrounding swamps, were vulnerable to a combination of flooding and salinity stress in experimental studies. Chinese tallow (*Sapium sebiferum*), a highly invasive exotic tree species, was tolerant to the combined salinity and flooding stresses associated with simulated storm surges. Flooding was more important than small increases in salinity in the growth and survival of most tree species tested, whereas large increases in salinity were harmful to all of the species tested regardless of flooding regime. It is evident that large-scale shifts and/or losses in wetland forest communities are likely to occur over the next 50 years if current trends in sea-level rise continue. Genetic studies conducted with baldcypress, however, also suggested that new varieties can be developed that might be planted in restoration projects and partially mitigate the effects of salinity intrusion. Significant variation in salt tolerance existed among baldcypress populations. Greenhouse and field experiments demonstrated that this tolerance has a genetic component and is heritable. These findings imply that restoration of baldcypress forests may be possible in degraded sites where existing populations have been killed by low-level saltwater intrusion.

At Big Thicket National Preserve in southeast Texas, scientists from Rice University established a long-term monitoring effort to detect coastal forest response to climate change. Permanent plots were established to quantitatively document the dynamics of forest structure and the responses to changes in storm intensity, flooding, and fire frequency. Long-term monitoring data suggest that increases in drought associated with changing climatic regimes may significantly alter understory seedling populations in bottomland forests, recruitment into the sapling layers, and ultimately influence overstory canopy structure. Flooding, hurricanes, and even low-intensity storms which result in openings in the forest canopy will influence the responses of these forests to climatic shifts by accelerating natural successional processes. Increased disruptions to the forest canopy will also provide recruitment opportunities for exotic species enhancing their rate of invasion into natural stands.

A series of related studies was initiated to determine potential changes in the growth and geographic distribution of forest tree species. Tree ring analyses from sites across the wet-dry transition zone from western Louisiana to central Texas suggest that many forest tree species do not alter their growth rates near the edges of their range. These results combined with forest tree dynamics from the permanent plots imply that seedling establishment and survival may be more important in limiting the geographic ranges of tree species than the growth and survival of adults.

Exotic species can be expected to increase in importance throughout forest stands in the coastal plain with increased levels of disturbance and canopy gap formation. The costs to control exotic species will continue to rise in national parks and other managed natural areas. Other shifts in species composition are also expected to occur. Increased disturbance from changes in the frequency and intensity of tropical storms may favor early successional, shade-intolerant species at the expense of shade-tolerant ones. Land managers will be faced with intensive efforts to maintain the natural character of their preserves.

Mangrove ecosystems predominate the coastal areas in the lower Florida peninsula where hurricanes commonly occur. Landscape simulation models developed by USGS scientists confirmed that hurricane disturbance has also contributed to the structural composition of modern mangrove forests across south Florida and Everglades National Park. Modeling future climate change scenarios with the results of this research suggests that increased damage associated with stronger storms will likely result in future mangrove forests of smaller stature than present day stands and that shifts in species dominance to stands composed of red mangroves (*Rhizophora mangle*) are likely to occur.

Assessment

The research findings summarized in this document reveal both the scale and scope of potential global change impacts on plant communities of low-lying coastal margins. While there remain many uncertainties regarding the regional and local responses to changes in climate, current studies of plant communities and landforms of the coastal zone of the southeastern United States provide strong evidence of the potential effects of relative sea-level rise and changes in tropical storm activity. Predictive models and new developments in remote sensing technology can be used to project the impacts and interactions of global change variables on land cover and geomorphology of the coastal zone. We cannot as yet verify the ultimate and cumulative effects on species, populations, and communities. In the southeastern coastal plain, however, we have documented trends in the changing dynamics of plant communities, loss of coastal wetlands, and erosion of barrier islands that can be related to more than 50 years of environmental change, regardless of causative factors. Future research should provide a more thorough understanding of wetland response to long-term environmental change.