White Paper

NOAA Workshop: Ecological Effects of Sea Level Rise in the Florida Panhandle and Coastal Alabama: Research and Modeling Needs

WORKSHOP BACKGROUND

The Center for Sponsored Coastal Ocean Research (CSCOR) is addressing the current and future problems to ecological systems due to the long term effect of sea level rise and erosion on coastal ecosystems through the peer-reviewed research program, the Ecological Effect of Sea Level Sea Level Rise (EESLR). Through competitive research, the goal of this program is development of models and maps to <u>accurately</u> forecast the response of coastal ecosystems to sea level rise. To accurately forecast these ecosystem effects, researchers must understand changes in habitat structure and coastal process offshore, in the shore zone and near-shore including the multiple associated interactions that drive these changes. Thus, the modeling teams often need multiple levels of local *in-situ* data and ecological rates to accurately predict ecosystem changes in a specific area. Development of such cutting edge models requires extensive mining of historic data well as research to 'fill in' data and knowledge gaps. EESLR works with state and local resource managers in order to integrate the long-term effects of sea level rise on benthic, inter-tidal, wetland and upland habitats including their ability to sustain their productivity with the potential increases in flooding and salinity. These forecasts will be invaluable for coastal managers in planning land management strategies as well determining locations for future restoration projects. Will the location be able to respond by 'keeping-up' with future sea level rise impacts and erosion? Our pilot project in North Carolina, which began in 2005, is currently in the final stages with interesting results becoming available and the next project, sited in the Florida Panhandle and Coastal Alabama, is slated to get underway in 2010.

In preparing for the new EESLR program in Florida and Alabama, CSCOR convened a Steering Committee of experts and hosted a workshop to ascertain relevant scientific data and knowledge and to develop an understanding of the environmental management needs in response to long term sea level rise and associated erosion of the Florida Panhandle and Coastal Alabama. The workshop was held on January 23-24, 2008 at the Environmental Protection Agency's Gulf Ecology Division in Gulf Breeze Florida. Attendees included local and national scientists and managers who identified relevant research questions and information needed to advance knowledge and predictions of interactions among sea level, shoreline change, bathymetry, coastal habitats, and ecosystem effects, and their application to coastal management. From the information compiled at this workshop, the Steering Committee developed this White Paper outlining the consensus of the workshop attendees regarding the requirements for scientific information and predictions and a research strategy for addressing these requirements. The Steering Committee will remain accessible and may be called upon periodically to review the program progress and suggest mid-course corrections.

The members of our Steering Committee are:

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Dr. Jesse C. Feyen, Coast Survey Development Laboratory, NOAA
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THE ECOLOGICAL CHALLENGE

Coastal ecosystems are vulnerable and in danger of losing ground to sea level rise in the future. The 2007 Intergovernmental Panel on Climate Change (IPCC) affirms that warming of the climate is unambiguous with global averages of air and ocean temperatures increasing, widespread melting of snow and ice, and rising global sea level. Global average sea level rose at an average of about 2mm per year between 1967 and 2003, with the rate increasing in the last ten years. The IPCC estimates that the eustatic sea level rise for the next century, based on various future carbon dioxide scenarios, will be between 18 and 59 cm. However, the IPCC did not accounted for ice dynamics, the more rapid movement of ice sheets due to melt water, which could markedly speed up their disappearance and boost sea levels. The relative sea level rise will not be uniform around the globe since local sea level rates will be further impacted by additional factors: local geomorphological change can result in a much greater rate of sea level rise from land subsidence due sediment compaction and extensive removal of ground water. In concert with increasing rates of sea level rise, wind driven erosion affects coastal ecosystems compounded by lack of sediment supply due to human alteration. Moreover, in many areas expanding coastal development is preventing the capacity of natural ecosystems to respond to sea level rise.

Coastal managers routinely make decisions that affect coastal ecosystems and have a need to consider sea level rise impacts into their decision support process. Sea level rise will have significant impacts on the condition and distribution of coastal habitats, the living marine resources dependent on coastal ecosystems, as well as human interactions with these habitats. Coastal habitats, such as submerged aquatic vegetation, oyster reefs, benthic areas, intertidal mud flats, beaches, wetlands and forests provide invaluable ecosystem services, such as buffering coastal communities from storms, floods and other hazards. Managers and planners, as well as coastal communities that depend upon these habitats, need accurate observations and information, ecological models and long term predictions that will show the on-the-ground, local effects of long-term sea level rise and associated coastal erosion. Easy to use, hands-on, science-based decision making tools will help understand what management and policy decisions are needed to protect these critical habitats for future generations.

The Steering Committee divided the attendees of the workshop into six topical groups in order to facilitate discussions: geomorphology and physical processes, subtidal habitats, terrestrial biological resources, water quality and hydrology, and modeling. The six groups discussed habitats, species, processes of interest, existing research and management initiatives and research and modeling needs. Each group discussion is summarized in this document, as well as recommendations from state managers from Alabama and Florida.

SEA- LEVEL RISE IMPACTS ON GEOMORPHOLOGY AND PHYSICAL PROCESSES

Accurate models that forecast ecosystem-response to sea-level rise must take into account changes in physical processes and coastal morphology. The physical processes (wind, currents, and sediment flux) are the ultimate drivers of geomorphologic and bathymetric changes, which define the distribution of coastal ecosystems. For example, the extent of intertidal habitat is largely dictated by the tidal amplitude and coastal gradient. In addition, important linkages between the morphology and the physical processes of coastal areas exist. Wave- and tide-induced currents and sediment flux shape an estuary through erosion and deposition. The overall wave energy of an estuary will increase as the fetch and depth of the estuary increases as a result of erosion and sea-level rise. The frequency and intensity of storms that impact a coastal area play an important role in shaping a coastline and redistributing habitats. Sediment compaction, isostasy, and fault movement are also important factors in changing elevation and bathymetry. Natural coastal processes and morphology are severely altered by humans and the percent of modified shoreline is on the rise as coastal populations increase. Watershed management (dams) and modifications (land-use changes, bridges, and causeways) impact coastal areas by altering sediment and water discharge. Clearly, forecasting changes in coastal morphology and physical processes in response to sea-level rise is more complicated than simply inundating a well-constrained topography and applying the present current and wave regime to the newly formed near-shore area.

KNOWLEDGE GAPS

The accuracy of models that predict changes in the morphology and physical processes of coastal areas as sea-level rises depends, in part, on baseline data. Models should also be verified and calibrated, which is commonly accomplished using historical (1-100 years) and geological (100-1000's of years) datasets of coastal change. Much of this information is lacking or is incomplete for the study area as a whole. Although the rate of global sea-level rise is predicted to increase in the future, these predictions cannot be blindly applied to local areas due to variations in tectonic settings. The study area borders the rapidly subsiding Mississippi Delta to the west, and encompasses part of the stable West Florida Carbonate Platform in the east. Information on vertical displacements within the study area is lacking. Sediment discharge (suspended and bottom sediment) of the major rivers in the area is unknown. This is important for determining sediment budgets for the estuaries as a whole and for individual habitat types. Vegetation aids in trapping sediment and contributes important organic material to the sediment budget. Rates of change in coastal wetland elevation, accretion, and vegetation cover are needed. Present rates of estuarine shoreline movement are also lacking. Detailed bathymetric data at near-shore locations are necessary to better constrain the wave and current regime at the shoreline and to better understand the exchange of sediment between the land, intertidal, and subtidal areas. The physical processes and morphology of the present-day coast need to be well constrained before modeling how these factors are modified by sea-level rise.

CONCLUSIONS AND RECOMMENDATIONS

It is clear that the most profound changes to coastal geomorphology will occur close to the land-water interface. Models will benefit from historical and geological studies that quantify past shoreline and ecosystem changes when physical processes and/or sea-level rise are well constrained. This is the only method for calibrating and verifying models. Additionally, geological data provide information on ecosystem potential for non-linear change. Models need to be built around a detailed map of habitat type, bathymetry, and topography close to the shoreline. The study area encompasses distinct types of shoreline including open ocean, low-gradient marsh, high-gradient scarp, and deltaic. Sediment exchange including rates of erosion and deposition at the shoreline need to be well constrained for the various shoreline types. Severe storms play an important role in modifying shorelines and their impact at the various shoreline types need to be constrained and incorporated into the models. Human modifications to the coastline (bulkheads, living shorelines, jetties, impermeable surfaces, etc.) may have larger impacts on future habitat distribution than the effect of sea-level rise. This needs further study and results should be incorporated into the model.

SEA-LEVEL RISE IMPACTS ON SUBTIDAL HABITATS

Subtidal habitats are areas subject to low mean tides that are permanently submerged (*sensu* Dauvin et al. 2007)*. Muddy and sandy sediments, as well as, “hard bottom” habitats will likely be subject to sea level rise effects, changing either physical (e.g., distribution, extent) or biological (e.g. community composition, abundance) variables. Presently, a clear understanding of the migratory dynamics of the associated communities to these habitats is lacking. Long-term sustainability and migratory capabilities of oyster reefs, as an example of hard bottom communities, require a better understanding of the dynamics of processes.

Sea level rise as the driving mechanism affecting change requires an integrated approach for the understanding of species which presently are at their environmental range limit. Studies focused on long-term monitoring, distribution and quantification of sediment trapping/accretion and determination of present and future biological parameters (geographic range, potential changes on life history/stages) are of the highest priority.

**DAUVIN, JEAN-CLAUDE, GERARD BELLAN and DENISE BELLAN-SANTINI. 2007. The need for clear and comparable terminology in benthic ecology. Part II. Application of the European Directives. AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS. Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/aqc.864*

Coastal managers are confronted with the need to take a preventive approach on their decision making, with the goal of incorporating ecological effects of accelerated sea level rise into the regulatory processes. Thus, restoration prioritization should be based on a comprehensive knowledge of present status and trends prior to determining what is critical to maintain ecosystems integrated and treated as a unit.

KNOWLEDGE GAPS

The rate of habitat loss due to climate change effects is largely unknown. Historical understanding of retreat by the different subtidal communities and how these communities have migrated in association with sea level rise is an area where very sparse data exist.

Comprehensive studies that recognize connectivity within the subtidal zone, and connectivity of this zone with near-shore and upstream habitats have not been implemented. It should be noted that the use and collection of standardized parameters, reflecting the geomorphological variation within the study area, will help to drive models. Regional values will facilitate the construction of models using consistent data; values derived from research will also initiate an environmental database for the region as an example of value added from these activities.

It is recognized that different systems will respond differently, and species and community ecological thresholds vary geographically. Comparative studies in geographically diverse locations have been minimal. The implementation of these types of studies is important to provide basis for the determination or not of generalizations.

Compilation of commercially or ecological population baseline data will serve to examine potential sea level rise impacts. This information could provide indicators of long-term change. Concurrently, a catalog of potential areas for retreat and restoration for these populations need to be determined.

Experimental approaches to understand the land/water interface and the saltwater-freshwater interface as well as how this transition varies have not been carried out in a systematic manner. Targeted studies of biological and physiological tolerances to changes anticipated from sea level rise will prove critical for the development of biophysical models.

CONCLUSIONS AND RECOMMENDATIONS

Understanding the present and future distribution of habitats to better prioritize restoration should be an overall objective. Experimental and modeling information should address this question. Ideally, the proposed studies are an extension of current research that will incorporate more extensive analysis of climate change variability and not only SLR. Multiple stressors ought to be researched simultaneously. Simulations must include extremes, ranges, and uncertainty and confidence values. Proposed models should present best-case and worst-case scenarios based on different assumptions and model and forecasts should include examples of where habitats will be, where they are now; and where shifts will occur. There's a perception that models need to go further and show the connection of what are the end consequences in terms of policy and/or economic impact.

Funded activities should focus on how does research inform policy as part of a collaborative effort with coastal managers. How will the information produced by research be communicated to managers? A clear example of a final deliverable ought to be a tool to answer societal needs, as determined by a joint academic-policy team.

SEA-LEVEL RISE IMPACTS ON TERRESTRIAL BIOLOGICAL RESOURCES

Coastal terrestrial habitats in Alabama and the Florida Panhandle that will be affected by sea-level rise and storm surges include various forest types (pine savanna, sand pine scrub, flatwoods, coastal hammock or maritime forest, bottomland hardwood forest, upland hardwood forest, bay-gum swamp and cypress swamp), marshes and prairie types (e.g., *Spartina* marsh, *Juncus* marsh, freshwater marsh, coastal prairie, and wet prairie), sandy coastal strand habitats, and rare habitats such as seepage slopes, pitcher plant bogs, and dune lakes. Although some of these habitat types exist inland as well as coastally, others exist only along the coast rendering them potentially more threatened by coastal change. Additionally, although many of these habitats are common, others, such pitcher plant bogs, and dune lakes, are rare and/or harbor rare species.

KNOWLEDGE GAPS

Uncertainty about how coastal terrestrial habitats will be affected by the combination of sea-level rise and storm surges falls into two broad areas: questions of how the environment and biota will change on specific sites and questions of how (or if) species and habitats can migrate inland as sea level rises.

Rising sea level, punctuated by the occasional hurricane and storm surge, are likely to change these systems through increased salinity and sediment movement, killing various species in these systems and, perhaps more importantly, affecting their ability to recover from disturbances, such as hurricanes, that these systems have experienced repeatedly in the past. Multiple storm surge, on top of sea-level rise, have the potential to cause large areas of vegetation change from glycophytic (salt-water intolerant) to halophytic (saltwater tolerant) communities. Large storm surge may saturate soils with salt far inland, killing or stunting the growth of large areas of gylcophytic vegetation, which would allow invasion of halophytes, though it may take several years for the vegetation to switch. It is well documented that factors that impede freshwater flows to coastal terrestrial ecosystems (e.g., drought, freshwater diversions, and structures such as road beds) often increase salinity and cause ecosystem change. Therefore, any tool developed to predict the ecological changes caused by rising seas and storm surges must account for changes in freshwater hydrology, including those under the control of humans at a regional level, such as water diversions and withdrawal, those under the control of state or local governments, such as development patterns, those under the control of local land managers, such as onsite creation or removal of barriers to fresh- and saltwater flows, and those outside the immediate control of any local entity, such as changes in precipitation that are part of global change. Although the responses of some species to increasing salinity and other disturbances are well known, tolerance limits for most species are insufficiently well known to allow prediction of their ability to tolerate and/or recover from projected environmental changes. It should be recognized that other factors, such as the establishment of non-native species, change in nutrient inputs, and changes in fire regime may also impact coastal habitats directly, changing their productivity, their species composition, their susceptibility to effects of sea-level rise and storm surge, and/or changing their ability to recover from disturbances such as those wrought by hurricanes and saltwater incursions.

It is commonly assumed that coastal terrestrial communities will migrate inland as sea level rises. However, barriers to migration, such as those posed by coastal development, which is prevalent along the Alabama/Florida Panhandle coast, may prevent such migration. Additionally, there is uncertainty about whether current coastal environmental conditions (e.g., those produced by combination of substrate type, flooding, and salinity regime) will simply move inland or disappear from certain areas as rising seas encounter different geomorphologic and hydrologic features. Lastly, there is uncertainty about the ability of various species to migrate. Some may spread readily as favorable conditions move inland and others may not, changing the composition of shifting communities and, perhaps, requiring intervention to facilitate the movement of some species to prevent their extirpation.

Uncertainties about species' tolerances and their abilities to migrate are due, in part, to a lack of a coordinated network of coastal terrestrial monitoring sites: a lack that prevents us from adequately describing even current and recent patterns of environmental and biotic change.

CONCLUSIONS AND RECOMMENDATIONS

A model that will predict how the environment and biotic communities will change in a spatially explicit way should provide a valuable tool to assist land managers and policy makers in protecting terrestrial coastal resources in the face of rising sea level. Such a model

- should predict changes in communities and, particularly, the fate of rare species and species of economic importance
- should incorporate a digital elevation model to predict environmental change
- should predict changes in important aspects of the physical environment, such as flooding, salinity patterns, and if appropriate fire regime and nutrient inputs. (Interactions among processes that affect flooding and salinity, such as drought, changes in hydrology, sea-level rise, sediment movement, deposition, compactation and erosion should be included.)
- should incorporate the reaction of important species to the predicted environmental change
- should incorporate information on rates of migration and the ability of species to migrate with spatial shifts in environmental conditions
- should include projected scenarios of coastal development with their impacts on hydrology, salt movement, migration pathways, and probability of non-native introduction

A system for monitoring changes would be useful.

It was noted that predictive tools, such as this model, will serve coastal reserve managers and policy makers in different ways. Coastal reserve managers are generally charged with managing a proscribed piece of land, often bounded by private land and/or development at the inland edge. They need tools that will allow them to predict effects of changes on the biota and to predict effects of local management efforts that might alleviate any negative effects on the biota. In this context, a spatially explicit model that predicts effects of local manipulations (e.g., addition or removal of barriers to species movement, freshwater flow, salt movement, and sediment movement) on elevation, the physical environment, and species performance would be valuable. With continued sea-level rise, however, efforts to preserve terrestrial biota in narrow, low-lying, coastally restricted patches of land *in perpetuity* is probably futile, and longer-term management requires broader coordination. Long-term management requires:

- identification and prioritization of habitat that could serve as corridors for migration inland
- information on how and whether species will migrate inland without active intervention.

In this context, a spatially explicit model that incorporates the factors identified above would also be useful. Such longer-range planning is often outside the scope of what private and public land managers can accomplish, give the constraints of managing specific, bounded patches of land. The tools needed for long-range planning are those that would aid policy-makers and land-planners in prioritizing and protecting promising future coastal habitat that may be currently somewhat distant from the coast and corridors for inland migration of habitats and species. To be of use to policy-makers, these tools should be able to incorporate economic impacts of change and provide very visual projections of future coastal conditions, predictions that are easily understood by the public at large.

SEA-LEVEL RISE IMPACTS ON WATER QUALITY AND HYDROLOGY

The estuaries and bays and adjacent Gulf waters of the west Florida panhandle region are noted for their clear waters. Waters often take on a light green hue, resulting from light reflected off the white sand bottom, tinted by moderately productive benthic algal communities, earning the region the name "the Emerald Coast." In parts of the region, still healthy seagrass meadows thrive in the clear shallows. These bays are also home to surprisingly productive fisheries, which support both commercial fishing and a vibrant sport fishing community. Waters are naturally more turbid at the western end of the region, principally in Mobile Bay and eastern Mississippi Sound, where distributaries of the Alabama-Tombigbee river system deliver a large volume of freshwater and sediments to the Mobile river delta and Mobile Bay. The Florida and Alabama portions of the coast share a micro-tidal environment and precipitation totals that are among the highest in the North America. Thus, these systems have in common an especially narrow ecotone defining the interface between freshwater and high-salinity saltwater environments.

These fragile brackish ecotone regions of the Florida/Alabama panhandle region could be especially vulnerable to sea level rise and hurricane storm surges, making it important to understand both the processes that have enabled them to adapt in the past and those that will be important to sustain healthy coastal ecosystems in the face of sea level rise in the future. Hydrologic processes, especially shallow groundwater, are one important area. Mean sea level affects movement of groundwater in shallow unconfined aquifers, impacting the height of the water table. Infiltration of sulfate from marine waters into groundwater results the presence of toxic sulfides in anoxic, saturated soils. Changes in water table height and sea-water intrusion into groundwater impact soil and groundwater chemistry, can drive changes in upland vegetation. In some places, one can already observe coastal forests dying, with herbaceous wetland vegetation taking their place. Hurricane storm surge can drive changes in the short term by introducing a sudden pulse of salt water to upland or freshwater environments, but sea level rise reinforces and sustains these changes. Even sub-tidal environments could be affected by hydrologic changes associated with sea level rise. For example, poorly understood sub-marine groundwater discharges into shallow littoral zones could decrease as a result of sea level rise, possibly affecting seagrasses communities in these areas.

Freshwater is a critical resource for estuaries, especially if they are to sustain their unique biota in the face of sea level rise and increased storm surges. Unfortunately, even though water is usually abundant, water resources in the region are in some cases under heavy demand and are sometime highly-managed. A recent high-profile example is the Apalachicola River, whose flow is regulated in Georgia (where it is the Chattahoochee River) in order to support industrial and other uses in the rapidly-growing Atlanta metropolitan area. Managing freshwater resources to sustain salinity-sensitive natural habitats in estuaries and tidal fresh environments could become more challenging in the face of sea level rise, especially when during dry periods, such as has been experienced recently. Hydrologic changes associated with sea level rise could also impact some of the relatively unique, high value ecological features of the Florida panhandle region, including Florida's springs, bog systems and coastal dune lakes.

Existing Research, Management, or Modeling Efforts

Although the Florida/Alabama panhandle region is not among the most studied places in the country, there are a number of organizations current collecting potentially useful data in the region. Some of the programs identified by workgroup participants include:

- NERRS system-wide monitoring program
  - Apalachicola Bay NERR
  - Weeks Bay NERR
- Gulf Coast Ocean Observing System (GCOOS)
- Florida Coastal Ocean Observing System
- Northern Gulf Institute (unspecified programs)
- DEP Aquatic Reserves (continuous monitoring)
- FWRI and FWCC Harmful Algal Bloom Monitoring
- Florida Department of Environmental Protection (FLDEP), Alabama Department of CRN (ADCRN), and Alabama Department of Environmental Management (ADEM) NPDES non-point programs
- St. Andrews Bay Resource Management Association
- Choctawhatchee Bay Alliance
- Florida Department of Health (Pathogen Monitoring)
- US Geological Survey

A number of potentially relevant research programs were also identified, including:

- Land/Ocean Interactions in the Coastal Zone (LOICZ) Modeling (B. Burnett, FSU)
- Land/Ocean Interactions in the Coastal Zone (LOICZ) Modeling (J. Chanton, FSU)
- University of Alabama, Ground water modeling

KNOWLEDGE GAPS

A number of research and modeling topics were identified by the workgroup as important to understanding impacts of sea level rise and storm surges on hydrology and water quality. The main focus was the interaction between land changes and water quality. Resource managers would like to understand which features of the landscape provide "ecosystem services," such as reduction of nutrient and other pollutant loadings to surface waters, what services would be threatened by SLR, and what quantity of these environments are needed to provide the services required to sustain a integrity of the natural systems. In particular, if sufficiently detailed and accurate projections of likely changes associated with sea level rise can be combined with the impacts of these changes on water quality, managers may be able to "get in front" of those changes by implementing policies to reduce the impacts or adapt to unavoidable natural changes. Similar land planning concerns include identifying where important habitats will be caught between receding shorelines and human development, or which sub-tidal habitats could be subject to degradation as a result of shoreline hardening or other measures to prevent land-loss.

Aside from land-focused issues, a many of the things needed for water quality management today are also important in the context of planning for sea level rise. It is important to have good models of nutrient loading, with the added information of how loadings to surface waters will be affected as coastal wetland and upland habitats change in response to sea level rise. Nutrient dynamics and water quality will also be affected by changes in estuarine hydrodynamics caused by sea-level rise. Finally, to adequately predict how sea level rise will impact coastal water quality and the natural resources within them, it may be important to understand all of the major biogeochemical processes, including benthic and planktonic nutrient cycling, plus connections to coastal food webs (e.g., fish and shellfish production).

CONCLUSIONS AND RECOMMENDATIONS

The magnitude of sea level rise and the time-scale of concern is an important premise for the research program and should be specified in the Federal Register Notice (FRN). A suggestion is to address the impact of a 0.5 to 1.0 m increase in sea-level during the next 50 to 100 years and the impact of increased frequency of major hurricane (Category 3 to 5) landfalls in the region on top of sea level rise. Recent hurricanes in the Pensacola area include Opal (1995), Ivan (2004), and Dennis (2005). Research might also address possible interactions with other ecological changes expected in the same time frame. These might include changes in rainfall, air or water temperature, and associated hydrological changes.

The spatial scale of interest should allow research, especially field research, to address processes at a small scale, but should emphasize a multi-disciplinary research program. Projects should develop and apply an approach to extrapolate conclusions to the entire study area. An alternative, less preferred approach is for a single project to be funded for new and existing research and develop an analysis of expected landscape-scale ecological change. This is a similar approach that evolved in CSCOR's pilot, the North Carolina Sea Level Rise Program.

The proposed research should emphasize research to address changes in the natural environment, not hazards to coastal infrastructure associated with sea level rise and storm surge. However, recognizing that humans are an inextricable part of the landscape, research may consider how coastal development impacts adjacent natural environments (examples: impact of bulkheads on littoral zone habitat, impact of coastal drainage systems on salt-water intrusion). These concerns have an impact on the time scales that the research should address. Specially, the time scales of concern for ecological effects should be at least as long as the time scale for planning critical infrastructure such as roads, water and wastewater treatment facilities and distribution systems. This would also help evaluate implication of sea level rise on best practices for restoration, since such projects also have a similarly long planned lifetime.

In order to reach the intended audiences, an important aspect of the research program is an outreach plan that will provide useable information at multiple technical levels. In addition to the research community, target audiences include resource managers, local governments and the public. Potential tools to facilitate communication of the possible effects of sea-level rise to the public could include:

- Data layers usable with Google Earth
- Visualizations or simplified models that can be run on average desktop computers for use by coastal resource managers
- Educations materials suitable for K-12 educators
- Guidelines for "restoration best practices" to increase long-term success probability in the context of sea level rise
- Public relations information that vividly depict the possible impacts of SLR in specific places (i.e. " Sea level rise and You" materials)
- Citizen group outreach and involvement in monitoring
- Video/DVD outreach materials
- Direct outreach to educate community leads through town-hall, community chamber of commerce
- Traveling exhibits

MODELING THE IMPACT OF SEA-LEVEL RISE

Computational models have been developed for many coastal habitats to aid in resource management. Hydrodynamic models exist which predict circulation, including water level, currents, temperature, and salinity. Water quality models track nutrient dynamics. Sediment transport models exist which describe sediment flux in coastal environments. Biological models have been developed to predict primary and secondary productivity or the viability of particular species as a function of environmental conditions. Landscape models predict habitat changes due to both physical and biological changes. These are just some examples of the types of models that can predict conditions and changes within coastal estuaries.

Considering the range of models out there, it is important to identify processes to model which are important to the ecology and could be affected by sea level rise. These include (but are not limited to):

- Water level fluctuations (mean sea level, tidal, non-tidal including storm surge)
- Currents
- Salinity
- Temperature
- Sediment transport, erosion, deposition
- Waves, coastal wave exposure, fetch
- Meteorology, storm intensity and frequency
- Water quality, nutrient dynamics, sediment/water quality interactions
- Vegetation, succession, habitat change
- Endangered species
- Built environment, shoreline hardening, anthropogenic impacts

The prediction of the ecological effects of sea level rise through computational models requires inclusion of a wide range of physical and biological processes over a large time scale. Furthermore, the models generally have been built, parameterized, and calibrated to predict phenomena of different scope and resolution than sea level rise. These factors combine to make modeling efforts complex and challenging, leading to a number of important needs that should be addressed.

Some important areas for modeling include: the change in the shoreline and habitats from surface water elevation, "the squeeze" from an inability of coastal habitats to move inland due to hardened human development and hydrological control structures, the change in the saltwater-groundwater interface and the increased groundwater table that would result from sea level rise, and the elevated water table effects that will extend inland of actual salt water intrusion, creating freshwater wetlands where none were before, causing septic tank failure in areas where they are already close to ground water, and a cascade of nutrient and contaminant effects that would result.

The processes of interest include: landform changes associated with sea level rise (coastal effects on inland; inland effects on coast);effects of extreme events (e.g., flooding, drought, hurricanes, storm surge, sea level rise, fire) on organisms and geochemical processes; habitat resilience (i.e., through accretion of sediment, etc.) and vulnerability (e.g., loss, fragmentation, succession) to sea level rise ; physical processes including nutrient cycles, hydrology, sediment delivery, and water quality (groundwater, saltwater intrusion, nutrient input) interactions; and sediment delivery and natural transport processes

KNOWLEDGE GAPS

First, sea level rise models need to address how to make predictions at a relevant time scale. SLR impacts occur over 50 to 100 years, while many models have been developed to simulate synoptic time scales (seconds to weeks). A sea level rise model needs to resolve the physics appropriate to the spatial scale of the problem; e.g. seasonal currents may be more important than hourly currents. Furthermore, modeling of the effects of SLR needs to effectively consider how the scale of impacts compares against other processes occurring over the same time frame. These other processes include storm surges, geomorphological changes (including erosion), hydrologic fluctuations, and anthropogenic impacts, among others. For example, if extreme storm surge events can cause erosion rates on the order of a meter, how can these events be combined with sea level rise impacts in long-term predictions? Similarly, many habitat responses and vegetation changes are a result of both long term trends and short term severe events. How will these combined effects be characterized in a model?

Second, effective models need to consider the extent and spatial resolution of the model required to make a prediction. Generally modeling requires a balance between resolution, model extent (domain size), and run time. Considering the long time frame of sea level rise predictions, what tradeoffs will be made that will still allow a model to meet EESLR program objectives? Additionally, how will the related factors of data accuracy and parameterization of sub-grid scale physics be handled in response to limitations in spatial resolution? For example, elevation datasets may exhibit RMS errors from 10 to 50 cm; does this affect predictions of 50 cm sea level rise? Also, physical parameterizations of sub-grid scale processes need to be implemented as a function of the dynamic range of interest.

Third, it is likely that considering the range of processes that need to be considered for predicting the EESLR, numerous models will need to be coupled. This could include models of hydrodynamics, habitats, biological productivity, species distribution, water quality, and so on. An effective prediction of the ecological effects of sea level rise will require sensitive attention to intermodal integration. The challenge will be to couple models with different time and spatial resolution, variables, accuracy, parameterizations, and so forth. This could require a modular framework driven by the desired outcomes important to the EESLR program which includes the processes important to the problem.

CONCLUSIONS AND RECOMMENDATIONS

The EESLR program addresses a challenging and important problem. Long term ecological predictions have a very large scope with a wide range of variables and unknowns. Similarly, there is a long list of models that could be useful in addressing this problem. However, in order for the project to be successful, it is important to narrow down the issues under consideration. This will guide the evaluation and implementation of models for the project. Otherwise, a wide ranging, disparate set of projects could be implemented which do not coordinate well and do not result in cohesive, concise outcomes useful for local managers.

Therefore it is recommended that the EESLR project management identify a set of key objectives that will guide the life of the project. One example would be to focus on providing predictions of habitat change. This would require all projects to produce this type of evaluation. Another approach would be to focus on specific ecological issues such as saltwater intrusion into groundwater aquifers. These two examples illustrated the tradeoff between breadth and depth of focus. Similarly, the project should define what area the model predictions need to cover: the entire project region or a subset of the area. There are many challenges to modeling that will impact how models are designed and implemented. The project objectives need to be laid out in advance in order to enable participants to plan accordingly.

Development of the model results should be coupled with the development of an outreach plan and program that will provide usable information at multiple technical levels. The primary target audiences are resource managers, local governments and the public. Possible outreach products and outlets include: mapping of different sea level rise scenarios, including scenarios based on IPCC predictions and scenarios that include severe events (such as new inlet creation); quantifying risks for a range of scenarios; map results at time scales cued to the lifetime of critical infrastructure; assessment of the effects of the built environment and zoning on the potential for natural migration of habitat and species (e.g., shoreline hardening, location of infrastructure, etc.); and tools to indicate best practices for restoration, including the implications of sea level rise on restoration projects. A preference to provide modeling tools that can run on managers' computers. Model scale is an important consideration since there is a need for large-scale regional products as well as small-scale applications. Therefore it would be beneficial if it were possible to be able to scale up some aspects of the model. Funded researchers that focus on smaller geographic areas could be asked to parameterize the model so that it could be applied at a large scale. In some cases, deeper exploration of smaller areas might be more valuable. Data availability (quality and quantity) is an important issue; the NC project was successful because a lot of data was available. There is limited information on wetlands for the panhandle study area vs. what was available in NC. Event data may be hard to interpret/generalize.

Modeling specifications should include guidelines for investigator interactions on model integration (including verification and calibration criteria). Digital elevation maps should be incorporated in the models showing geographic effects of SLR, rate of rise, elevation, and freshwater/seawater inflow, changes in geomorphology; and map distribution of habitats, forecast changes to habitats and species ranges due to sea level rise. Risk assessment of sea level rise in coastal habitats should include a mapping component to assess "hot spots" of sea level rise; model physical/chemical processes affected by SLR, including tides, currents, salinity, temperature, waves, storm intensity; valuate ecological consequences of SLR at different temporal (50-100 years vs. synoptic) and spatial scales (local extrapolated to regional, landscape); potential for non-linear change in ecosystems.

MANAGEMENT PERSPECTIVES: FLORIDA

The Florida coastal portion of the study area is occupied by densely populated urban and commercial areas, protected lands and waters, and important biological land and water resources. Resource managers and those persons responsible for land use and growth management will need to be armed with accurate, useful technical information and predictions in order to be able to determine feasible adaptation strategies that protect the state's natural resources and prepare communities for changes in water elevations and increasing intensity and frequency of storm surge.

Model results need to present detailed, mapped baseline information on the geophysical and biological characteristics of the several basins in the study area, including the distribution of habitat and species of concern, in order to estimate and predict successional changes in coastal ecosystems, and how the species supported by coastal aquatic and terrestrial systems will change. Information on basin characteristics may be found in a number of publications. The basin assessments prepared for development of total maximum daily load (TMDL) are particularly useful and may be found at: http://www.dep.state.fl.us/water/tmdl/stat_rep.htm

In Florida, the range of geographic areas of interest includes rivers, forests, floodplains, freshwater wetlands, bays, marshes, seagrasses, dunes, and estuarine and marine waters. Resources of particular importance, however, include longleaf pine forests; steephead ravines; seepage streams and springs; scores of rare and imperiled plant and animal species and their critical habitats; commercially and non-commercially important fisheries; specially designated public land and water-bodies (state parks, aquatic preserves, national seashore); designated shellfish harvesting areas; aquifer and surface water sources of drinking water and irrigation water; submarine spring discharges; and rare or exceptional habitats such as high dune bluffs, the globally imperiled coastal dune lakes, and pitcher plant bogs.

Estimating ecological changes will require baseline analysis and understanding of the geomorphology, hydrology and biology of the watersheds in the study area. Florida Panhandle bays and estuaries are geophysically diverse. For instance, some receive drainage from very large watersheds, while others are small with little to no freshwater inputs. Some bays have narrow inlets and are, therefore, poorly flushed. Extensive estuaries exist behind a string of barrier islands.

Analyses of ecological change will require thorough understanding of coastal circulation; sediment characteristics and movement; groundwater and surface water hydrology, quantity and quality; locations of public drinking water supplies and well heads; and the presence of developed areas and shoreline structures that would affect or be affected by ecological changes related to SLR and storm surge.

MANAGEMENT PERSPECTIVES: ALABAMA

Natural Hazards

Hurricanes
Based on recent storm seasons and predictions by climatologists, the risk of tropical storms and hurricanes has increased and the Alabama Coastal Area will continue to be at a higher risk level for some time to come. Without man-made restoration efforts, beaches and dunes will have little time to recover between storm events. In areas not subject to large scale beach nourishment and dune restoration projects, this will lead to increased vulnerability to storm surge even from minor hurricanes.

Flooding and Storm Surge
Within coastal counties (Baldwin and Mobile), urbanization, increased development in flood-prone areas and increases in impervious surfaces have increased the potential for flooding, even in areas that had not previously flooded. Additionally, due to erosion caused by Hurricanes Ivan and Katrina, some areas such as the developed west end of Dauphin Island, have become more prone to storm surges and coastal flooding during minor storm events.

Chronic Erosion
The chronic erosion risk remains high. As documented in the “Beach Topographic Monitoring for 2004-2005; Short-termed Shoreline Change Analysis for 1990-2002 and Episodic Change and Erosion from Hurricane Ivan, 2004, Baldwin and Mobile Counties, Alabama” report, the Alabama Gulf-fronting shoreline continues to experience widespread erosional trends. Additionally, even with the on-going large-scale beach

nourishment projects, which did provide additional protection, the recent major hurricane events have produced large scale reductions in beach profile height and shoreline recession. Shoreline recession on the developed west end of Dauphin Island continues to be especially severe.

Areas in the coastal zone (by type/location) that posses sensitive coastal resources (e.g. wetlands, water bodies, fish and wildlife habitats, threatened and endangered species and their critical habitats) and require greater protection from cumulative / secondary impacts of growth / development.

Alabama Coastal Area	Cumulative & Secondary Impact Threats
Interior Bays and waterways of Gulf fronting communities, including Terry Cove/Cotton Bayou in Orange Beach, Intracoastal Waterway in Gulf Shores, and Dauphin Island.	The residential development trend in these areas is transitioning from single family and duplex development to large townhome and condominium developments. Tied to this is a growth in the number and size of private, multi-slip residential docking facilities. The explosion of this type of development in the Foley cut of the Gulf Intracoastal Waterway prompted the US Army Corps of Engineers to require an Environmental Impact Statement and carrying capacity determination for the waterway.
The "Foley Waterfront," including Bon Secour River and Wolf Bay.	Foley is the fastest growing municipality in Baldwin County. Within its city limits and planning area are the Bon Secour River and Wolf Bay watersheds. Condominium proposals have surfaced in Bon Secour and a major north-south thoroughfare is proposed for Wolf Bay. There are two large landowners in the Wolf Bay area and how their properties build out over the next decade will be significant with regard to cumulative and secondary impacts to coastal waterways. Unlike the Bon Secour River unincorporated area, Wolf Bay is under county zoning.
Bayou La Batre/Coden (Mobile County)	Historically known as a subsistence fishing and seafood processing area, the communities of Bayou La Batre and Coden in Mobile County show signs of population growth and development pressure. The seafood industry ails from an economic slump due to pricing pressure from imports. The Town of Bayou La Batre and a large developer have entered into discussions about public-private partnerships to transform the area to a tourist destination. Some type of development is expected within the next five years.

Impacts to Habitat and Fisheries due to Sea Level Rise

Cumulative impacts to air, water, aquatic plants, habitat and threatened and endangered species within Alabama's coastal counties include sediment-loading from erosion at development sites, increased impervious surface run-off, decreased natural cover, loss of critical habitat, emissions from additional industrial sites and vehicle and boat traffic.

Oyster Fishery

Oysters successfully inhabit a limited hydrological stratum. This stratum is saline enough to provide appropriate nutrients to the oysters but has a sufficient freshwater input to limit the oyster drill population and the dermo population. Any hydrological change (such as a mile break in Dauphin Island) that pushes higher salinity waters over the reef could result in a long term decline in the oyster reef. Depending on hydrological parameters, more successful oyster reefs would more further north - likely making marginal reefs like Whitehouse and King Bayou reefs more productive. However, these reefs remain more susceptible to freshwater input from the delta and may not reach the level of productivity currently seen on Cedar Point.

The fishery would follow the reef further north but, as the environment changes, during a transition period the oyster fishermen may compete for limited resources and over harvest the oysters. The oysters are quite resilient and will survive but many oystermen may lose their livelihood. Also, the tonging equipment currently used by the majority of the fishermen provides a depth limitation to the waters they can harvest. Currently, oyster dredges are high restricted in Alabama. Changes in regulation could occur but not all oyster fishermen would be able to afford the new equipment associated with the dredge.

Blue Crab and Shrimp Fishery

The effects of sea level rise on shrimp and crabs, and all estuarine species, will vary significantly depending on the actions taken to combat water intrusion. In the north central Gulf, shrimp and crabs are considered to be habitat limited rather than recruitment limited; if our response to sea level rise is additional ‘armoring’ of the fringe marsh then a decline in population can be expected. Juvenile estuarine species utilize the nooks and crannies of marsh edges to serve as shelter from predation and a safe place to seek prey – flat walls, like that seen in bulkheading, will reduce the habitat available for juvenile marine species.

Another effect would be the relocation of species further north to seek lower salinity, more estuarine waters. Habitat selection, including temperature, salinity and substrate preferences, strongly influence temporal and spatial distribution of species and life history stages. As marine waters inundate the coast, marine species will relocate to appropriate habitats. Some species may not be able to adapt as effectively and could be supplanted by other species. Anecdotal information from Alabama Marine Resources Division’s Fisheries-independent Assessment and Monitoring Program (FAMP) reveals the changes in abundance of some species over time, in particular Xiphopenaeus kroyeri (Seabob-a shrimp) and Stellifer lanceolatus (Star Drum). While no cause for this increased abundance can be determined, these two species have gone from rare, and incidental catches to fairly common species in certain locations.

The shrimp and crab industries are already economically stressed due to foreign imports and fuel costs. These industries, already in decline, would likely decline even further.

Currently, commercial fishermen are effective because they understand the way the ecosystem works and can maximize their profits by selecting times and locations that have been historically productive. As the ecology changes, commercial fishermen will have to expend additional energy adapting to the new circumstances. This change has already been noted in Alabama following the cut made in Dauphin Island following Hurricane Katrina. This cut has effectively made an additional 'pass' which has increased salinity and faunal exchanges and has provided another exit for shrimp from the sound. In summer of 2007, one experienced fishermen noted the effects of the cut by exclaiming "it's like I know nothing about these shrimp"; he has shrimped for over forty years. Even a small reduction in efficiency, given the economics already in play, will cause some fishermen to exit the industry. Those remaining will survive due to the Forrest Gump Effect – fewer fishermen will share a larger part of the pie.

SAV and Marsh/Wetland Habitats

It is more difficult to predict the effects on submerged aquatic vegetation (SAV) and wetland plant species. According to scientists, any number of impacts could occur. It may be possible for SAV to survive as long as the increase in sea level does not contribute to murky water environments, as SAV thrive on the availability of sunlight for production. However, if sea level rise causes a higher influx of sediment, as many believe that it will, SAV will die off due to blockage of sunlight.

Marsh plants have a number of potential impact scenarios for sea level rise. The level of negativity of the impacts will depend upon the marsh plants' ability to extend at rapid enough rates. Plants at the water's edge of the marsh will die off due to water inundation, but the marsh could extend landward depending on several factors. As mentioned, the first factor will be the rate and ability to grow landward. Marsh plants may not be able to grow fast enough to replenish the marshes and wetlands. Another factor is the land available for growth. Shoreline development such as homes, bulkheads, and other buildings will be a constraint as to how far landward these plants can extend. Without available land to extend into, it is possible that some areas will die off completely.

Sea level rise will also have an impact on species inhabiting marshes, specifically the rails of coastal Alabama, several of which are of moderate conservation concern or higher. These birds nest on or close to the water's edge, thus putting them at greater risk to sea level rise. The nests can be relocated according to rising water levels, but only as far as the marsh extends. These species require a certain density of plants to surround the nest. If the marsh grass cannot extend landward due to too slow a growth rate or development behind the marsh, the rails will be unable to nest and breed.

Data Efforts and Needs

Mapping/GIS/tracking of hazard areas

The ACAMP, Alabama Emergency Management Agency (AEMA), Geological Survey of Alabama (GSA), and the South Alabama Regional Planning Commission (SARPC), other state agencies and local units of government have all pursued additional GIS capabilities during recent years. This has resulted in the greater capability to plan for and respond to natural disasters. ADEM is pursuing the purchase of GIS hardware and software to increase its capabilities. Additionally, the ACAMP is working with SARPC and local building officials to develop a GIS based building permit program that will assist in tracking development in hazard prone areas. Once both of these projects are in place, the ACAMP and local building officials will be able to share GIS data, allowing for better tracking of development in the Coastal Area and increasing the capability to prepare for and respond to major storm events.

Other data needs include LIDAR data and landscape modeling for coastal Alabama. With these data, we would be better able to determine the impacts of sea level rise, as well as other natural hazards. Research needs include current and historical sea level data to include into models in order to determine how quickly sea level is rising in the Gulf of Mexico. Another need of researchers is water table data to determine surface flow and groundwater flow. This data would be able to help researchers and modelers in their efforts to help resource managers.

Significant impediments

Given the increased frequency of major tropical storm events, it appears that the base flood elevations and V-zone designations on the Federal Emergency Management Agency flood plain maps for many areas in Mobile and Baldwin Counties may be inadequate. However, local communities appear to be addressing these issues through adoption of the International Building Code and the requirement for increased free-board. Further, while state, federal and local policies and programs have provisions that discourage building in hazardous areas, the high demand to be in these areas has resulted in continued development, even with increased costs for construction and insurance. Given current development pressures, potential damage from coastal hazards is likely to increase.

Priority needs or major gaps in addressing the programmatic objectives for Alabama (i.e., inadequate authority, data gaps, inadequate analytical methods, lack of public acceptance)

Major challenges in addressing cumulative and secondary impacts are the following:
1) Limited authorities to regulate land use.
The lack of home rule in unincorporated areas continues to be a significant obstacle in terms of being able to manage land use and protect water quality.
Aside from the Alabama Coastal Area Management Program wetland regulations, there are currently no state authorities concerning wetlands.

2) Underutilization of existing authorities and regulations. A perception exists that enforcement of existing federal, state and local land disturbance regulations is neither fully diligent nor effective.

3) Data Challenges.
a. Data collection has historically been limited, particularly with respect to spatially oriented data. High-resolution land cover data for Mobile County remains needed.

Integrated, cross-agency monitoring, tracking, and sharing of land disturbance data should be a common goal.
b. Data sharing has been an historic obstacle. Limitations include lack of political will, data security/sensitivity, and funding for high tech solutions. Consistent data collection protocols, including the development of interagency standards for geospatial data management are needed.

4) Public Interaction
a. Apathy regarding land-use issues.
b. Limited awareness of cumulative and secondary impacts by the majority of citizens and public officials.

CONCLUSION

The Florida Panhandle and Alabama coast is an area of diverse coastal habitats with a wide variety of shoreline types represented, including high-gradient cliff type shorelines, low-gradient marsh shorelines, and deltaic shorelines. Profound changes to coastal geomorphology will occur close to the land-water interface making historical studies that quantify past shoreline and ecosystem changes necessary. Sediment exchange including rates of erosion and deposition at the shoreline need to be well constrained for the various shoreline types. The possible regime shifts in these shoreline areas will be profound. The increasing trend of hardening estuarine shorelines and modifying sediment and water transport pathways adds a lot of complexity to the problem of better understanding the ecological effects of sea-level rise; thus human modifications could really be the true driver of future ecological change.

Sea level rise will affect benthic, sub-tidal and terrestrial environments. Targeted studies of biological and physiological tolerances to changes anticipated from sea level rise will prove critical for the development of biophysical models. Historical understanding of retreat by the different communities and how these communities in the past have migrated in association with sea level rise is needed. The connectivity within the benthic zone with near-shore and upstream habitats need to be understood as well as the land-water interface and the saltwater- freshwater interface.

Understanding the present and future distribution of habitats to better prioritize restoration should be an overall objective The ability of species to migrate with spatial shifts in environmental conditions should include projected scenarios of coastal development with their impacts on hydrology, salt movement, migration pathways, and probability of non-native introduction identification, thus allowing prioritization of habitat that could serve as corridors for migration inland. Experimental and modeling information should address this question. The use and collection of standardized parameters will help to drive models as well as a catalog of potential areas for retreat and restorations for these populations need to be determined.

The time scales of concern for ecological effects should be at least as long as the time scale for planning critical infrastructure such as roads, water and wastewater treatment facilities and distribution systems. This would also help evaluate implication of sea level rise on best practices for restoration, since such projects also have a similarly long planned lifetime. In order for the project to be successful, it is important to narrow down the issues under consideration. This will guide the evaluation and implementation of models for the project. Otherwise, a wide ranging, disparate set of projects could be implemented which do not coordinate well and do not result in cohesive, concise outcomes useful for local managers. Most importantly, continued involvement of managers in processes of model and tool development is essential for success.

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