Ecological Effects of Sea Level Rise
A new research program sponsored by the NOAA's
Center for Sponsored Coastal Ocean Research

Introduction

This document lays out the rationale, approach, and expected products for a new research program supported by the Center for Sponsored Coastal Ocean Research (CSCOR) within the National Ocean Service (NOS) of the National Oceanographic and Atmospheric Administration (NOAA). The Ecological Effects of Sea Level Rise (EESLR) research program is designed to help coastal managers and planners better prepare for changes in coastal ecosystems due to land subsidence and sea level rise. In the coastal United States, ecological impacts due to sea level rise have already been significant and will likely increase. Planners need to begin weighing the impacts of future sea level rise when making land use decisions, especially in vulnerable shallow near-shore environments and coastal wetlands, which provide important habitat for a number of commercially valuable fish and shellfish. More proactive approaches are needed rather than regulatory protection alone. Since state governments have the primary responsibility for developing strategies to mitigate adverse impacts, CSCOR's approach is to work with state managers to develop plans that will best respond to their needs. CSCOR's sea level rise program will provide managers with an 'ecological forecast' (Clark et al., 2001) using modeling and mapping tools. This ecological forecast will help managers and planners to better assess and predict the fate of ecologically and economically valuable natural resources threatened by sea level rise.

EESLR is starting with a pilot program in the State of North Carolina. The North Carolina Division of Coastal Management's Strategic Planning Unit is involved in the planning and focusing of the research program. CSCOR is also working with NOAA's Office of Coast Survey (OCS), National Geodetic Service (NGS), and Center for Operational Products and Service (COOPS). EESLR has a four-stage approach to modeling sea level rise in coastal North Carolina which will be used to predict and assess the ecosystem impacts of sea level rise. Stage 1 is a hydrodynamic tide model of Pamlico, Albemarle, Core, and Bogue Sounds and adjacent estuarine and coastal waters. Stage 2 is a high-resolution, topographic/bathymetric digital elevation model (DEM) which integrates recent airborne LIDAR (Light Detecting and Ranging) topographic data and bathymetric data. Stage 3 is a hydrodynamic coastal flooding model which integrates the DEM and the tide model. The coastal flooding model includes coastal land and water and will be used to predict and assess the sea level rise impacts in the Pamlico and Bogue Sounds and the Neuse River. Stages one, two and three are accomplished in-house combining the resources of OCS, NGS, and COOPS.

Stage 4 is a suite of ecological sub-models that can be integrated with the coastal flooding model, and will be developed through extramural funding provided by CSCOR. The end result will be a model coupling the physical models (DEM and hydrodynamic coastal flooding) with ecological models demonstrating landscape responses relevant to critical natural resources. Where sufficient information currently exists, these ecological models can be developed within a relatively short time. In other cases, gaps exist in the data and understanding needed to add ecological models to the physical models. Further research will be essential to understand ecological processes, feedback mechanisms, and vital rates. This necessary research will be accomplished through requests for proposals from the extramural research community, funded through the CSCOR peer-review process. In this way, academic researchers will work collaboratively with NOAA modelers to assemble a product useful to local managers. Through this four stage approach, we hope to construct high resolution mapping tools developed through modeling ecological response to sea level rise. The resultant ecological forecast will be the handiwork of modelers and managers working collaboratively to address natural resource problems created by sea level rise. The ecological forecast will focus scientific research and monitoring priorities to reduce uncertainties in future planning.

Management Needs

North Carolina has over 300 miles of ocean beaches and over 4000 miles of estuarine shoreline. Much of the this area is less than 20 feet above mean sea level (MSL) with large percentages being less than 5 feet above MSL. A rising sea level will have significant adverse effects on the state's environment, public health and economy. The impacts of sea level rise will vary by location and depend on a range of biophysical characteristics and socioeconomic factors, including human response. The primary impacts of sea level rise are physical changes to the environment. These changes affect human uses of the coast, such as tourism, development, transportation, commercial and recreational fishing, agriculture, and nature viewing activities. The most important effects of sea level rise are the gradual inundation of wetlands and low dry lands, erosion of beaches, more frequent and severe flooding, and greater salinity of rivers, bays, aquifers, and wetlands.

Sea level rise presents a serious challenge for North Carolina. However, in general, this issue has not been a priority for many coastal communities as they plan for future growth and land use. Local governments are encouraged to begin considering the impacts of future sea level rise when making land use decisions. Damages and economic losses could be reduced if local decision-makers understand the potential impacts of sea level rise and use this information for planning purposes.

Tools and Information Needed to Address Sea Level Rise

More proactive approaches are needed to plan for sea level rise, mitigate impacts and educate local officials and citizens. To assist with this effort, managers need useful modeling and mapping tools to better assess and predict the fate of ecologically and economically valuable natural resources threatened by sea level rise. The development and refinement of a digital terrain/hydrodynamic model for North Carolina that integrates ecosystem changes in response to sea level rise, currently the focus of NOAA's Center for Sponsored Coastal Ocean Research, will help coastal managers and planners better prepare for changes in coastal ecosystems due to land subsidence and sea level rise.

These models and maps will reveal which areas are most vulnerable and in most need of immediate attention.

More informed decisions would be made related to land use practices that affect our commercial and recreational interests. Over time, armed with additional information, local governments can better address their ability to respond to the threat of sea level rise.

Developing Effective Management Strategies

The model and maps and other information resulting from the EESLR Program will be developed with one goal in mind- utility to managers. As managers identify the information needed to make the best day-to-day as well as long-term planning decisions, the EESLR program will provide relevant models and mapping tools. These maps and tools will be used to forecast the ecological response to sea level rise and indicate which land areas, habitats and plant/animal species are most vulnerable to sea level rise scenarios and thus aid in prioritization of land areas, habitats and/or species for protection and additional recognition. Managers can then prioritize the affected habitats according to the “value” they provide to society. Environmental management is about making compromises, and managers need to identify the most important habitats to protect so that when negotiating the compromise, the best information is available to support a position. Such proactive management strategies and effective policy development will result from the modeling and mapping tools developed from the EESLR Program. Once habitats are defined and mapped, appropriate management strategies can be developed. This could involve special designation through the NC Coastal Area Management Act (CAMA) as Areas of Environmental Concern (AECs) and/or through the CAMA Land Use Plan Land Classification process, or other appropriate avenue of special land classification and designation process. Appropriate development and resource protection guidelines could then be developed for activities within these areas.

The modeling and mapping tools can help managers assess the migration of submerged aquatic vegetation (SAV) as well as coastal wetlands and other wetland types. Information would be used to identify natural and man-made barriers that would impede the habitat's natural transgression patterns and to delineate important natural boundary areas. Modeling tools should indicate where there are current barriers to habitat migration, and where future barriers need to be designed to protect existing infrastructure. It can thus be used as a tool to request/secure funds from the General Assembly (and others) for land acquisition, resource mapping/evaluation and infrastructure protection.

The information gleaned from models can be used to educate local planners, citizens, property owners and decision-makers regarding local impacts of future sea level rise. It could help in assessments of infrastructure (e.g., sewage, roads, and septic tanks) impacts. The map resolution should enable the tracking of individual land parcels and should be of sufficient scale for delineation of specific properties with sufficiently accurate to withstand any legal challenges. Ideally the risk manager can alter SLR changes (magnitude, rate) in concert with changes in other stressors (e.g., land use, hydrological regimes) to learn of their cumulative effects over time. The SLR models and maps could therefore be part of a decision support system. Will wetlands be able to migrate landward? Will wetlands species composition change as salinity increases? Similarly, what will happen to SAV beds as waters deepen and salinities increase? What about turbidity – will the water become clearer, allowing greater light penetration and enhancing high salinity SAV? Will oysters be able to "move" upstream (and how far?) as their preferred area of moderate salinity moves? All of these "what ifs" can be considered by a planner with the proper tools. Good modeling and mapping tools could allow experimentation allowing alteration of various environmental stressors and physical characteristics such as salinity, turbidity, temperature, storm surge weather. The manager can then consider the various future possible scenarios.

Many of NC's most important habitats are in shallow water (SAV, shell bottoms, wetlands) that would be affected by sea level rise, especially if there is a major breach/loss of the Outer Banks, converting the Albemarle-Pamlico system into high salinity bays. Maps of current habitat locations and tools to create hypothetical scenarios of what may happen to these habitats would be very useful. System changes attributable to sea level rise will cause area-specific changes in fish behavior, thus affecting fish movements and shifts in fishing areas and strategies, requiring adjustments in fisheries management responses. Accurate impact projections and mapping will be essential to develop timely management responses.

There are critical issues and management questions that models and modeling tools can help address. For example, are the current overall wetland areas "holding their own," expanding or contracting? Where are the critical landward wetland migration areas and what development activities are currently taking place within them? What are the species of plants and animals that inhabit these migration areas and what are their tolerances and thresholds related to a changing environment? Good forecasting will enable managers to develop techniques to provide for a landward wetland expansion zone. Additionally, accurate, comprehensive forecasts of underwater habitat are needed for use in fish-stock assessment, design of marine protected areas and other resource management issues. These forecasts can be integrated into a good management support system. Managers must work with modelers to decide what physical and biological characteristics define important habitats. Then models can be developed with these defining characteristics alterable to represent various possible scenarios with various rates of future sea level rise.

Other questions can be answered through a good management support system developed from the EESLR Program. What is the maximum rate of sea level rise that such management techniques can operate under? What are the environmental impacts associated with shoreline erosion control structures and how are these affecting wildlife/fishery habitats? What effect has barrier island development had on back barrier wetland habitat producing processes and total back barrier wetland area? What effect has inlet alteration had on wetland habitat dynamics and total inlet related wetland area? What are the physical characteristics and spatial distribution of different substrate types in shallow, nearshore areas of the NC coast? How fast will the sea level rise in the future compared to historical rates? And of course, the BIG QUESTION – Will that future rate be faster than our marshes can keep up with? The EESLR Program will strive to help managers make educated guesses to answers some of these enigmatic questions.

Research Plan

Short Term 2004-2005

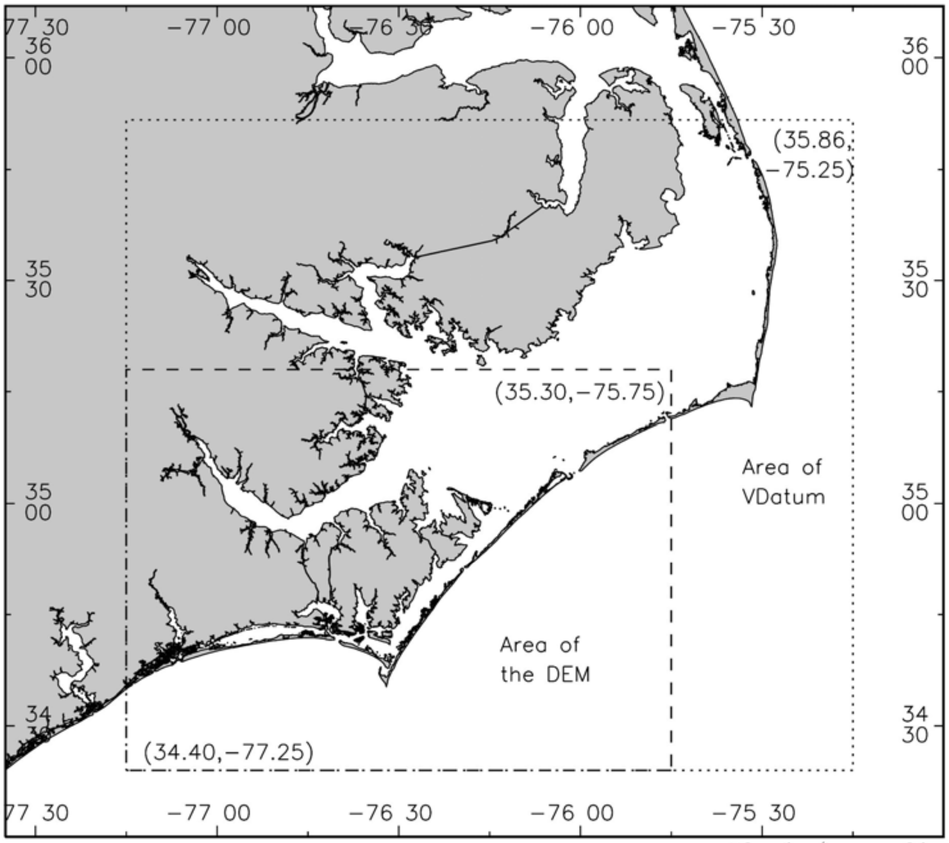
This project is the continuation of the NCCOS-funded North Carolina Sea Level Rise study begun in FY2003. The goal of the project is to predict and assess the impacts of rising sea level on coastal wetland and forest ecosystems in Pamlico, Core, Back, and Bogue Sounds and the adjacent lands in Pamlico, Craven, and Carteret Counties. The physical aspect part of the project has five major components: (1) the VDatum software tool for the central coastal area, (2) the hydrodynamic model, (3) the bathymetric/topographic digital elevation model (DEM), (4) the coastal flooding model, and (5) management tools. Work was begun on the first three components in the first year, and the first two components are nearly complete. The activities described below are planned for completion in the coming year (May 2004 to May 2005).

The project staff will complete the task of applying VDatum for the selected geographic area (Fig. 1), so that the bathymetry can be re-referenced to a common vertical datum such as NAVD 88. VDatum is a NOS software application that converts among approximately 29 vertical datums, including tidal, orthometric, and three-dimensional datums. VDatum is a prerequisite to creating the DEM. Tasks include generating the VDatum marine grid and populating the grid with tidal datum fields and sea surface topography.

The hydrodynamic model, which is substantially complete, will be used to simulate the influence of winds on water levels in the sounds. If time and resources permit, wind waves will be added to the model, and a three-dimensional version of the model that incorporates salinity and temperature will be tested.

The DEM will be completed when the bathymetry is combined with the land elevation data from the State's topographic LIDAR survey to produce the bathymetric/topographic elevation model, with a spatial resolution of 10 to 30 m in the horizontal. USGS personnel are also producing a DEM of the same area, possibly of higher spatial resolution, and the project staff plans to exchange data with them.

The coastal flooding model (CFM) combines the tide and water level model and the DEM. The CFM will be developed by expanding the existing tide model grid to cover low-lying land areas and then populating the grid's land cells with DEM-based elevation values. Elevations will be in a uniform vertical reference frame such as NAVD 88 or NAD 83 (86). The DEM will be revised to include roadways, drainages ditches, and other features affecting inundation. The CFM will then be used to assess land inundation due to storm surges and sea level rise. The CFL will be designed to be able to incorporate surface and subsurface flow, wetlands, and intertidal areas.



The Pamlico Sound area of North Carolina showing the region of the DEM and of VDatum. The DEM is defined on the lower left by point (34° 24' N, 77° 15' W) and on the upper right by point (35° 18' N, 75° 45' W). The VDatum area is defined by the same lower left point, and on the upper right by point (35° 51.6' N, 75° 15' W).

Management tools that include maps of inundated areas and other new information may be developed and accessed as work on the DEM and CFM progresses. The goal is to significantly improve the ability of coastal managers to assess the potential ecosystem changes due to rising sea levels.

Mid-term

The mid-term goal of this project is to fund research proposals through a peer-reviewed call for proposals. The Federal Register Notice soliciting proposals was published on June 30, 2004 (FRN Vol. 69, No. 125, p. 39428). This call for proposals is primarily to mine data that has already been collected through federal, state and local agencies and universities, and use that data to begin ecological modeling that will link with the DEM and hydrodynamic models. Any new data collected during this phase must be vital for model construction and/or input. Modeling will be the key tool to link existing data and information on biological communities to the NOS modeling efforts. It is important that the researchers specify the time and space scales needed to link biological/ecological models and also specify the key variables that will drive the linkages. Researchers should consider local importance of the questions being addressed through the proposed models and should include evidence of linkages between the scientific questions and management needs. Ideally, local managers and/or state natural resource agencies should be part of the research team. The model or models must relate to the environmental goals and address one or more specific recommendations from the sea level rise workshop. Similarly the model must relate the results to the reference and benchmark conditions- in order to evaluate the consequences and significance of results. These models must have enough flexibility to extend results to other coastal ecosystems.

<u>Long-term</u>

Long term research will include field and laboratory studies to provide information and data identified in this document as currently lacking, and necessary to understand and model EESLR.

A very important outcome of the EESLR program will be the development of tools to make the modeling results easily accessible to managers. Validated models could be used to make predictions about the effects of proposed management activities giving decision makers useful information that would not be available from empirical data. These tools must have user-friendly characteristics such as ease of changing inputs to reflect different management options, and scenarios and outputs that are visual and synthetic.

An important consideration is the transferability of the model in some form to other areas and states with similar biological and physical characteristics as North Carolina. For example, how can these models be transferred to wetlands where *Spartina* and *Juncus* are not the dominant species?

Workshop Description

CSCOR hosted a workshop in February 2004 in Beaufort, North Carolina to receive guidance from the research and management community in the major areas of investigation needed to help coastal managers mitigate the regional ecological impacts of sea level rise. CSCOR invited approximately fifty experts to the workshop. Local state invitees included individuals from the NC Division of Coastal Management with expertise in strategic planning and coastal hazards, the NC Division of Water Quality, the NC Ecosystem Enhancement Program, the NC Division of Marine Fisheries, the NC Wildlife Resources Commission, the NC Division of Forest Resources, the Albemarle-Pamlico National Estuary Program, the NC Division of Emergency Management, the NC National Estuarine Research Reserve Program, and the NC Coastal Resources Commission's Science Panel on Coastal Hazards. Academic scientists from the University of North Carolina, Duke University, East Carolina University, North Carolina State University, University of South Carolina, University of New Orleans, Louisiana State University, University of Virginia, Johns Hopkins University, Clemson University, California State University, Rutgers University, McGill University and Western Washington University were involved. NOAA partners included the Office of Ocean and Coastal Resource Management (OCRM), Office of Coast Survey (OCS), National Geodetic Service (NGS), and Center for Operational Products and Service (COOPS). Other Federal representatives included the US Geological Survey and the US Fish and Wildlife Service. Non-governmental scientists from the North Carolina Environmental Defense and the Nature Conservancy were also at the workshop. A complete list of contributors to the workshop is in Appendix II. A plenary session on the first day introduced the program and discussed early steps taken in modeling SLR. Breakout groups discussed critical knowledge and gaps in the areas of physical processes, marshes, forested wetlands, and habitat use. After the workshop, it was recognized that a separate group should focus on Submerged Aquatic Vegetation, and *post-hoc* input was requested from experts in this field.

The goal of the workshop was to identify critical scientific knowledge needed to predict the fate of ecologically and economically valuable natural resources threatened by sea level rise, prioritize knowledge gaps, and develop research strategies to address these gaps in a relatively short (2 year) time frame.

Study area

The EESLR Program will start the modeling program in a limited area of North Carolina, the Albemarle Pamlico Estuarine System (APES). APES differs from coastlines north and south due to absence of astronomic tides which means that a major mechanism of sediment transport responsible for vertical accretion is missing. Factors controlling the response of wetland to rising sea level will also differ from areas where tidal marshes prevail. The APES estuarine system is a complex of fresh to brackish water creeks. The aquatic environment is typically oligohaline where the average salinity usually does not exceed 5 ppt. The Pamlico, Albemarle, Core, and Bogue Sounds and adjacent estuarine and coastal waters are included in the hydrodynamic model. However, the coastal flooding and ecological models are limited to the Pamlico and Bogue Sounds and the Neuse River. In the area of study, sea level is rising at 3-3.5 mm/yr (Chris Zervas, NOAA, personal communication). The rise is faster to the north of the region and slower to the south. Because of the low regional slope, this unremarkable sea level rise produces major and rapid rates of lateral response characterized by extensive shoreline recession. The resulting flooding of the land is initially up the topographically low river valleys and then laterally across the uplands. As the land floods, the shoreline moves inward.

Wetlands

Coastal wetlands represent a state intermediate to the transition from the two extremes of strictly terrestrial and aquatic landforms. Rising sea level is the “master variable, the continuous and chronic force, that forces the process of change overall” (Brinson et al, 1995). Understanding the underlying mechanisms that mediate the relative importance of biotic and physical mechanisms is essential to understanding the controls on vertical accretion and erosion at the estuarine margin. This data is needed to make reliable predictions on the effects of accelerated rates of sea level rise

An important question is whether coastal wetlands will be able to persevere amidst increases in rate of rise in sea level and possible changes in frequency and intensity of coastal storms. The sediment to maintain wetlands in a setting of rising sea level is derived either autochthonously through in-situ primary production, or allochthonously from transport of inorganic grains in the clay-silt size range. The relative magnitude of the allochthonous supply and the excess of in-situ primary production over decomposition determine whether a particular wetland soil is dominated by autochthonous organic mater or allochthonous mineral sediments. Extensive low-lying autochthonous peat lands lie on APES peninsula. (Michener et al, 1997).

If the wetlands do not receive enough sediment, salt stress works synergistically with waterlogging to diminish primary productivity. Sea level rise will thus impede propagation of marsh and the associated wave action will initiate and accelerate erosion and micro-cliffs will form. Creek intersections with marsh can widen and deepen and extend-toward the head of the estuary as the wetland is submerged. If land is low-lying, the habitat zonations will also move landward. The zonations may widen, or narrow and grow together. Landward migration is impeded when the surrounding area is a sharply greater elevation. Zones may be compressed or disappear as sea level rises. This also happens when land is cultivated for agriculture and sea walls are built. If sediment supply is not adequate, the marsh terrace will cease to exist and coast or sea walls will be bordered by mudflats or sand flats. If sea level continues to rise – these too will become submerged (Bird, 1993)

Intertidal area

Sandy and muddy intertidal sediments will be modified as SL rises. Submerged Aquatic Vegetation (SAV) require suitable substrate, generally mud or sand, and light penetration limits them to low tides with depths of less than 10 m. Their growth is impeded by strong current and turbid water caused by the release of substrate sediment. Increased wave energy as SL rises may generate greater turbidity and /or steepened gradient. Broad plains with nutrient-rich soil, however, may increase sea grass beds. (Bird 1993)

Change of State

Continuous sea level rise ultimately causes an ecosystem to convert through increased inundation. Whether through astronomical tides, wind waves pushing water levels onto the marsh, storm surges, precipitation or fresh water run-off, inundation allows sediment to be trapped by the vegetation or lost in water run-off. As the water rises relative to land, SAV changes to deeper heterotrophic benthic systems, intertidal mineral low marsh changes to SAV, mineral low marsh transforms to organic high marsh or high marsh changes to upland or wetland forest. This transformation from one ecosystem class to another is called a state change (Brinson, Christian and Blum, 1995). When inundation becomes permanent due to sea level rise, state change occurs. Or, as inundation deposits enough sediment onto the marsh to cause an increase of vertical elevation, state change can also occur.

For example, in some areas of the APES brackish marsh have invaded pocosin communities. The peat surface of pocosin that is above sea level becomes the platform for an invading marsh community. This transition zone is potentially wide-spread and it commonly takes the form of a marsh dominated by *Juncus roemerianus*. Apparently, salinity is responsible in part of this invasion (Brinson, 1991). Brinson, Bradshaw and Jones (1985) studied the change of a forested wetland to marsh and observed the first phase of the transition appears to be the death of trees that dominate the upper canopy and replacement by mixed scrub and herbaceous plant populations. The second phase would be replacement of scrub community with brackish marsh. These phases are controlled by rising sea level and accompanying increased salinity.

Transition between states involves a combination between gains and losses that seem to be the response to disturbance such as erosion and wrack deposition and stresses from the osmotic effect of salt, low redox conditions due to flooding and accumulation of toxins such as hydrogen sulfide. These changes in state - summarized as upland or wetland forest, organic high marsh, intertidal mineral low marsh, autotrophic benthic with or without submerged aquatic vascular plants, and heterotrophic benthic - are well described in Brinson et al. (1995).

Breakout Group Summaries:

I. Physical Processes Workgroup

Coastal wetlands, comprising salt-marshes, mangroves and intertidal areas, are sensitive to sea-level rise since their location is intimately linked to, and partly determined by, sea level. However, they are not passive elements of the landscape and, as sea level rises, the wetlands respond. Intertidal areas will be steadily submerged during a tidal cycle for progressively longer periods and may die due to waterlogging, causing a change to bare intertidal areas, or even open water. On the other hand, the surface of any coastal wetland may rise due to increases in sediment and organic matter input, or the wetland may migrate upland if there is sufficient space and no barriers. Therefore, coastal wetlands show a dynamic and non-linear response to sea-level rise. Understanding the physical processes is imperative to understanding the rise, as well as forecasting future effects of sea level rise. Without specific adaptations by ecosystems or humans, sea-level rise will significantly increase the flood risk and eventual loss of coastal ecosystems.

<u>Processes</u>

Physical processes describe the motion of the water and its contents, the air, and the underlying sediments in an estuary and coastal ocean that are due to primarily physical (i.e., non-biological and non-chemical) forces. These processes include fluctuations in the water surface (astronomical tides, wind tides, storm surges, and wind waves), the flow of water through the basin (currents, river flows, salinity, temperature, and turbidity), the flow of water through the soil (subsurface hydrology), changes in landforms (erosion, sedimentation, and accretion), the effects of the atmosphere (winds, precipitation, and evaporation), and impacts of human activity (dredging, alterations of drainage, and beach protection).

Many of these processes are inter-related or are due to several causes. For example, water level variations are due to astronomic tidal fluctuations on the continental shelf and to the action of the wind over the water. Winds produce long-period water level variations (wind tides) and short-period wind waves, as well as infrequent but short duration storm surges that inundate normally dry land. Water currents within estuaries are due to several causes, primarily to astronomical and wind tides, but also to river flow, water density differences, and atmospheric pressure changes. The currents produce mixing of fresh river water and salty ocean water, and erode and carry sediment. Subsurface flow of water changes salinity. Finally, the atmosphere, in addition to supplying winds, also affects the water balance water via precipitation and evaporation.

Relationships with Other Processes

Physical processes have an important impact on, and are influenced by, the ecological processes in the coastal area. Water levels have a large influence, since mean water level, astronomical tide range, and wind tides determine how often during a day or week coastal wetlands are inundated. Wind waves play a part in the erosion at the marsh-water interface, and storm surges flood coastal vegetation with brackish or saline waters. Water currents affect plankton and aquatic vegetation, and bring salt, nutrients, and sediments to wetland edges. Subsurface flow of water changes salinity at the water's edge.

State of Knowledge and Some Knowledge Gaps

The following list describes, in no particular order, a summary of the knowledge of the major physical processes active in the study area and brief comments on the gaps in that knowledge.

1. The APES differs from coastal areas north and south due to the varying and often small astronomic tides, which means that a major mechanism of sediment transport responsible for vertical accretion may be absent. Differing from areas north and south where tidal marshes prevail, factors controlling the response of wetland to rising sea level will also differ. Wind tides, a major influence in the APES, are, like astronomic tides, a persistent process that determines morphology, wetland type and distribution, and are responsible for nutrient, salt and biotic exchange. The knowledge of wind tides is locally good (i.e., known at specific locations where observations have been taken) but regionally lacking.

2. Atmospheric processes such as coastal fronts, tropical and extra-tropical cyclones, evapo-transpiration, and, precipitation, are episodic and seasonal phenomena that help to determine the morphology, wetland and upland vegetation type and distribution as well as delivery of nutrients, salt and biotic properties. The current knowledge is locally good, but regionally lacking, especially for inundation.

3. Storm surge is an episodic process that helps to determine erosion and morphology, wetland and upland vegetation type, and distribution as well as delivery of nutrients, salt and biotic properties. The current knowledge about individual storms and the surges they produce is good for some well-studied events, but the paucity of water level stations in the APES means that other events have not been assessed.
4. The knowledge of the hydrology of (i.e., flow of water through) surface and subsurface wetland and upland (including tidally flooded dendritic ramp and platform marshes as well as irregularly flooded and ditched wetlands) is currently patchy and lacking for small scales. The knowledge needed includes residence time, material input, output and transport, wetland distribution and function, and water column and benthic community structure and function.
5. The knowledge of the hydrology of the estuaries and sounds is locally good, except for open sound currents. Needed for modeling are residence time, material input, output and transport, upland habitat, wetland distribution and function, and water column and benthic community.
6. Information about water salinity, temperature and turbidity helps understanding about stratification, chemistry, biogeochemical cycles, salt water intrusion, and bio-optical properties and is locally good but regionally variable.
7. Wind waves can cause erosion and shoreline movement, sediment re-suspension, transport and deposition, and can help determine geomorphology and habitat type. Prediction ability is adequate but there is little wave data in the APES.
8. The geologic framework, both surface and subsurface, is generally well understood generally but inadequate specifically.
9. Bathymetry, topography, and geomorphology determine drainage patterns as well as inundation and habitat type. Topography is well documented by the recently-collected LIDAR elevation data. Bathymetry data is good in the inlets and major deep waterways, but is poor especially in near-shore and inter-tidal areas.
10. Sedimentation within wetlands, tide flats, estuarine basins, perimeter platforms, shorelines and scarp/marsh edges is responsible for maintenance of wetlands and channels and sediment balance and is very poorly known.
11. Knowledge of human impacts/modifications including erosion control structures, ditches, wetland disturbance, run-off and land cover changes, roads, dikes, spoil banks and beach stabilization is not well documented.

Priorities for Research

The Workgroup established the following priorities (Table 1 below) for the various processes and variables. Processes as ranked for their important for the model system. Research was ranked highly only if the process was highly important but the state of knowledge was low.

Table 1. Physical process, with their importance and research needs.

Category	Process/Variable	Important for Modeling	Important for Research
Water Levels	Long term sea level rise	High	Low
	Astronomical tides	Medium	Low

	Wind tides	High	Low
	Wind waves	High	Low
	Storm surge	Medium	Medium
Hydrology	Hydrology of marshes	High	High
	Hydrology of land: surface & subsurface	Medium	Medium
	Circulation in estuaries and sounds	High	Medium
	Fluxes through inlets	Medium	Medium
	Salinity, temperature, turbidity	High	Medium
	Sediment and organic supply to wetlands	Medium	High
	Precipitation and evapotranspiration	Low	Low
Geology	Surface, subsurface geology	Medium	Low
	Shoreline Change	High	High
	Inter-tidal Topography	High	High
	Wave Erosion	Medium	High
Human Impacts	Shore protection	Medium	Medium
	Fishing	Low	Low
	Landward construction	High	High
	Marsh drainage	Medium	Medium

~~4.~~ Data Availability

Data for the study is likely to be available from (1) long-term observations at numerous locations, (2) a limited number of single-use observations at a few locations, (3) the scientific and technical literature, and (4) wide-scale remote sensing.

Water level and wind/meteorological data is available from NOAA through observations at various locations around the study area, and water levels and river flow rates are available from USGS and the State of North Carolina at a limited number of additional locations. Wind wave data may be available at a few locations from NOAA or the State and its universities. Information on the hydrology of marshes may be available in the scientific literature, as may be data on surface and subsurface hydrology, and sediment supply to wetlands. Water circulation (current), salinity, and temperature data are likely to be available from observations at a limited number of locations. There may be limited observational information about the flow of water, salt, sediments, and nutrients through the inlets. Surface and subsurface geological data is likely to be available from the State.

Shoreline change and elevation data is likely to be available for small, widely-scattered areas. Wave erosion and fishing impact data may be available in the scientific literature. Shore protection and landward construction data may be available from the State.

Conclusions and Recommendations:

Conclusion: The knowledge of astronomic and wind tides and atmospheric processes is locally good but regionally lacking.
Recommendation: Data mining for historical water levels are needed, and numerical modeling will be necessary.

Conclusion: Knowledge of storm surge is lacking
Recommendation: Study needed with numerical modeling and including inundation

Conclusion: Knowledge of the hydrology of uplands and marshes is inadequate. Salinity, temperature and turbidity are not well known.
Recommendation: Study flow through marshes and subsurface flow from land. Simultaneously measure fluxes of salinity and turbidity through inlets and mixing in sounds.

Conclusion: Information about the shoreline and surface and subsurface geology needs to be mapped in the study area
Recommendation: Geological map needed of study area, including shoreline type and change.

Conclusion: Bathymetry needed for large parts of the study areas.
Recommendation: Measure intertidal and shallow water depths and elevations, possibly by using tide-coordinated Lidar

Conclusions: Sedimentation information lacking
Recommendation: Study shoreline wave erosion, sediment supply to marshes and inorganic accretion, fluxes throughout the sounds, and bottom sediment type

Conclusion: Human impacts and modifications are important
Sedimentation: Data mining and mapping of channels, barriers, and roadways through Lidar and other remote sensing.

II. Marsh Group

Acceleration in the rate of sea level rise during this century has prompted a need for studies to better understand how marshes might respond to this potential threat. Coastal marshes are an important ecosystem of North Carolina's Coastal Plain. They provide many ecosystem functions including supporting diverse food webs sustaining resident invertebrates, fish, birds and mammals. Many economically important fish are dependent on these marshes during part of their lifecycles. In addition to biological importance, marshes provide buffer to the upland regions, providing storm and flood protection. The marshes in this geographical region are geomorphically low lying areas with very gentle slopes, low lying streams and poorly drained soils. Our ability to accurately calculate the future distribution of North Carolina's marshes with the impact of sea level rise will ultimately depend on how well we understand factors controlling their expansion, losses and repositioning. Planned ecological models in the EESLR Program should incorporate the ways the ecological processes will affect water level

The marsh working group divided the marshes into non-tidal (fresh, and salt/brackish) and tidal (fresh, salt/brackish). The major factors that regulate the zonation and growth of marsh communities are water salinity and soil salinity. Since salt content gradually decreases as tide water moves inland, plant species with similar salinity tolerance occur in bands paralleling the shoreline. Some species have a wide tolerance for salt, will grow in a wide range of conditions and will be found in all marsh types. Water depth and tide range also affect the distribution of plant species. The continued sea-level rise will increase the depth of coastal waters and alter the salinity gradient inland. This alteration in salinity gradient may cause upstream salinity intrusion and may greatly affect brackish and freshwater wetlands. Because of the relatively small tidal range in North Carolina, a narrow slope may support a wide range of plant communities. However in the non-tidal western Pamlico Sound, astronomic tides are irrelevant to sea level controlled wetlands. Within a salinity regime, plant species occupying a specific site are usually determined by the nature of the soil, whether silts, clays or organic matter.

Non-tidal Marshes

Non-tidal marshes are mostly freshwater marshes, although some are salt/brackish. Wind tides are not regular, reoccurring or predictable as are astronomical tides. When certain wind events occur, brackish to fresh water, depending on the location gets pushed up onto the marsh or forested wetland surface. For this reason, most of the species listed for tidal fresh water marshes in Odum (1984) are not found in the APES. A noteworthy gap in tidal freshwater marsh distribution occurs in much of North Carolina where the types of plant communities typical of most east coast of US freshwater areas are restricted in size and replaced by tidal swamps. The notable exception to this is the Cape Fear River system. Future studies will probably need information about ecosystems such as Cape Fear that are more typical north and south of APES.

Tidal freshwater marshes

Tidal freshwater communities have plant species that are similar to non tidal marshes listed above. Tidal fresh water marshes are not very common in North Carolina because most tidal freshwater wetlands in the State are forested. However, the working group emphasized the importance of considering tidal freshwater marsh in this modeling activity so that when the developing ecological models are applied to other regions where freshwater tidal marshes occupy a greater proportion of the landscape, the models will be applicable. The potential response of tidal fresh water marsh to sea level rise by mineral deposition and organic matter accumulation is unknown. The geomorphologies of these marshes are characterized by sand and peat soils that are rich in organic matter, but the upper limit of peat accretion is unknown.

Tidal saltwater and brackish marshes

Tidal salt water and brackish marshes are normally categorized into two distinct zones, the lower or intertidal marsh and the upper or high marsh. The lower marsh is normally covered and exposed twice daily by the tide. Most of the water for plant growth comes from seawater in the lower salt marsh, but the upper marsh is often heavily influenced either by abundant freshwater from the land drainage and flooding or the occasional catastrophic storms that floods the entire marsh with seawater. Salt marshes of North Carolina are dominated by *Spartina alterniflora*, which thrives on the outer edge of the marsh that regularly receives inundation. Higher in the marsh *S. patens*, a shorter *Spartina* species which thrives in areas with higher salinity is found although *S. alterniflora* can dominate along channels and ditches within the high marsh, where regular inundation occurs. In this way, *S. patens* is on the drier and saltier side of *S. alterniflora.* Very resistant to salt stress, *Distichlis spicata* grows abundantly, often mixed with *S. Patens*, in the dry, hyper-saline upper marsh, as does *Juncus roemerianus*. Salt/brackish marshes include mainland fringe marshes that have mineral sediments and are subjected to high boat-generated wave energy; back barrier fringe marsh with variable amounts of organic materials depending on over wash frequency. Tidal marshes in the APES have negligible astronomic tides signifying that sediment transport mechanism would be limited to storm events. Due to the basically non-tidal nature of the APES, there is no high marsh except near the ocean inlets.

<u>Knowledge Gaps: Marsh Responses to Sea-Level Rise</u>

The working group named the physical drivers that are marsh systems determinates. These include astronomical tides, salinity, sediment supply (both reworked and oceanic) marsh position relative to scarp and marsh gradient relative to spatial extent. North Carolina's coastal geomorphology is particularly sensitive to sea level rise because of its low relief and marsh and forested wetland vegetation. Fringe wetlands have extended seaward over the last 3500 years to generate current estuarine geomorphology, because rates of sedimentation have exceeded the rate of sea level rise. Early indications of geomorphologic breakdown should be apparent due to recent sea level rise rate acceleration. Early signs of system change could include a landward shift of the brackish water ecotone. This transgression occurs as a mixed diversity, rather than as a simple linear shift of vegetative habitats. Another sign of system change could be barrier island tidal pools, with only ground water connections to the sea, increasing in size.
Any modeling effort will need to incorporate these external drivers. Knowledge of the variability of the drivers and their distribution within the landscape must be a part of model parameterization.

Knowledge gaps identified by the working group include a critical need to understand the spatial patterns of marsh categories and other landscape units and how these categories/ units interact with one another. How a marsh responds to sea level rise is partially dependent on substrate characteristics (sandy, clay or peat). Accretion rates of organic material both above and below ground are essential for modeling if marsh vertical and horizontal changes will keep up with sea level rise. Also critical is an understanding of erosional affects on marshes, especially how marsh edges are affected by erosion and how changes in the edge affects their function such as utilization of the habitat by animals. (Odum, 1984)

<u>Processes Affecting Vertical Accretion</u>

Surface accretion is vital for the maintenance of the marsh under conditions of gradual sea-level rise. Processes controlling vertical change include organic matter accumulation, which in turn is determined by the balance among organic matter production, decomposition, and export; sedimentation including deposition of new or reworked mineral sediments or sediment erosion; and shallow subsidence through compaction and decomposition. An important factor in all of these processes is substrate composition. Additionally, understanding of the geologic processes that impact regional rebound or subsidence is vital since this feature is embedded in the relative sea level rise.

Organic matter

First of importance is net organic matter accumulation through production, decomposition and export. The factors controlling gains and loses in primary production and distribution of the biomass need to be well understood. There is a possibility here of working in conjunction with the on-going Cape Fear River Project headed by workshop participant Courtney Hackney. Excess primary production of organic matter over decomposition produces soil that is rich in organic material from autochthonous origin. The surface of these marshes must keep pace with sea level rise or their productivity will become suboptimal. Above ground production for these marshes are well understood but below ground production processes need study. Decomposition rates both above and below ground need more study. Very little is known especially about below ground decomposition. Some analyses done on vertical cores can give information about the rate of accumulation during sea level rise in the past. However past sea level rise may not be as rapid as the projected rate future rate of rise. In marshes fringing estuaries with water table controlled by sea level rise, vertical accretion might be influenced by rising sea level. In contrast, this is not true for inland marsh where sea level is not the main water table determinant. It is not known where the interface occurs between these two controls (Moorhead and Brinson, 1995).

In addition, more study is needed for the effects of bioturbation of salt/brackish marshes cause on biomass export and oxidation. A recent study (Thomas, 2004) looks at the role of bioturbating organisms in export of organic material and in enhancing decay of belowground materials. Other types of burrowing animals could have significant local impacts. It is not clear how much of an impact bioturbation would have at the landscape scale.

Inorganic Sedimentation

Mineral sedimentation of marshes and its effect on vertical accretion also need study. On ocean dunes and on estuarine areas affected by astronomic tides, knowing mineral sediment accretion rates is vital to modeling marsh process changes due to sea level rise. Little is known about the effect of pulsed events on sedimentation rates. Rich organic material in the extensive low-lying peat lands that occur in APES suggests low inorganic mineral input in this area. Because local astronomical tides are minimal in range, the major part of the deposition of fine grain material on the salt marsh is associated with high winds. Movement of allochthonous materials, primarily inorganic minerals in the clay-silt size range is thus limited to storm surge deposition and aeolian sources in the Pamlico- Albemarle Sound and adjoining estuaries. Sedimentation through tidal flat erosion and deposition may be a source of materials for vertical accretion. Little is known about the *Juncus* rate of change for this process nor is data available for the effect of extreme events on the extensive *Juncus* marsh.

Shallow subsidence

Shallow subsidence resulting from compaction and ground water flux is also an important influence on vertical elevation. These processes are not well understood.

Processes affecting Horizontal extent of marsh

Erosion

Erosion, the physical removal of organic or inorganic material, causes a reduction in size of marsh. Daily on-shore winds as well as high energy storm winds cause high energy waves that erode the marsh edge thus causing a diminution in marsh. In North Carolina, the extensive *Juncus roemerianus* marshes are more prevalent than marshes dominated by *Spartina*. They are in the process of eroding around their edges in many areas. From a vertical perspective, they seem to be keeping up with rising sea level at the present time. Moorhead and Brinson (1995) suggest that understanding the controls of vertical accretion and shoreline erosion are necessary to project future sea level rise. If current rates of rising sea level continue, accretion will prevent submergence, and erosion rates alone will be adequate to predict changes in wetland area and position, Due to a lack of understanding of shoreline erosion controls, we cannot currently predict shoreline changes

Inundation
The inundation regime determines marsh type and controls state change. Inundation of the marsh by sea water and fresh water can occur not only by astronomical tides and wind tides and waves but also through creeks that meander causing both erosion and accretion.

Salinity

Salinity changes are another process controlling marsh horizontal reduction and state changes. Again, threshold values and mechanisms are needed to identify salinity effects. Sea level rise may cause the saline fresh water interface to move upstream/ upland. Further, inland salinity intrusion can become more important that disturbance in controlling the species in submerged grass beds. Salt intolerant species will die with enough of a salinity increase. Most halophytes have an enormous range of tolerances. *S. alterniflora* is somewhat special in its capacity to both tolerate salinity and inundation.

Extreme disturbances

Extreme disturbances such as fire, hurricanes, herbivory, invasive species and anthropogenic effects can have thresholds that when crossed initiate reduction of marsh and state change. With hurricanes that transport brackish water landward, effects can be long-lasting since the hydrologic mechanisms for removing salt are poorly developed. The intensity, duration and type of the thresholds needed to initiate state changes depends in part on what the change actually is, such as forest to high marsh or high marsh to low marsh, low marsh to lake etc. In order to model and predict state changes, rules are needed to identify when state changes are likely to occur.

Conclusions and recommendations:

<u>Vertical processes controlling elevation change-marsh maintenance</u>
Organic matter accumulation
Conclusion: Organic matter accumulation rates through production are needed for all types of marsh. Production rates are known for above ground processes, production rates of below ground processes are unknown for all marsh types.
Recommendation: Above ground organic matter production rates are known for all types. The data needs to be mined and assembled to determine organic matter accumulation. Organic matter accumulation data collection is need for below ground for all marsh types. Researchers should focus on communities dominated by *Juncus* in non-tidal and *S. alterniflora* in tidal salt and brackish habitats

Conclusion: Little is known about below ground organic matter loss rates through decomposition for all marsh types.
Recommendation: Decomposition rates both above and below ground are needed for all marsh types through data mining or data collection.

Conclusion: New research has shown a potential of loss of organic matter through export due to bioturbation
Recommendation: Studies needed to determine the effect of bioturbating organism in the export of organic matter and in enhancing decay of below ground materials.

Sedimentation
Conclusion: Sedimentation through deposition is critical as a source of material responsible for vertical accretion
Recommendation: Sedimentation rates for all marsh types are needed using radioisotopes and pollen analysis to insure a variety of time scales.

Shallow subsidence
Conclusion: Shallow subsidence through compaction and ground water flux are critical control of vertical elevation.
Recommendation: Survey marsh substrate bulk density profiles and use the survey to estimate compaction with cohort modeling approach.

<u>Horizontal change processes- state change</u>
Erosion
Conclusion: Erosion rates are needed for marsh edge. It is measured for Cape Hatteras and north and possibly other places.
Recommendation: Use existing wave exposure model.

Inundation and salinity
Conclusion: Inundation regime and salinity determine marsh state. Change in depth due to sea level rise can account for higher inundation levels. Sea level rise may cause the saline fresh water interface to move upstream/ upland. However, this can be overwhelmed by changes in inlet position and size, as well as by other cross sectional changes in tidal creeks.
Recommendation: Data mining where appropriate. Appropriately controlled field/mesocosm experiments are needed to determine physiologic tolerance/thresholds to support state change models. It must be done with plants from NC because of population genetic variation and appropriate soils

Competition
Conclusion-Competition between species can be an important component of state change.
Recommendation: Harper-White competition experiments (non-greenhouse) needed.

Disturbance (fire, hurricane, floods, anthropogenic, herbivory, disease)
Conclusion: Ecosystem disturbance can initiate a state change
Recommendation: Experiment of opportunity (using proscribed burns, clear cutting, etc.) and field experiments are needed. Also change analysis based on historical information can be used.

III. Forested Wetlands

Forested wetlands in North Carolina are highly productive and dynamic environments and encompass the majority of North Carolina's brackish and freshwater wetlands. The forest ecosystem encompasses a range of environments. The same suite of processes impact these various environments, although the relative importance changes. The environments that are most likely to be impacted by a change in sea level are those either at low elevation or in swamps, in which groundwater levels will change as sea level changes.

Forested wetlands can be categorized into six types. 1) Forested tidal swamps extend along rivers in the continuum from brackish water to fresh water and occur on rivers such as the Neuse and Pamlico. Brackish tidal swamps include forests of cypress, black gum, and ash while freshwater tidal swamps include cypress, gum tupelo and red maple. 2) River swamps are similar to the tidal swamps in tree species, although the herbaceous cover differs, as the plants must be adapted to more continuous inundation. 3) Pocosin habitats are chronically flooded by rain water, rather than by rivers or tides. They often have limited circulation and typically have a peat substrate. Atlantic white cedar is common in pocosins. 4) Pine flatwoods occur on flat, but irregularly drained, substrate. They may be unmodified, but have often been modified to become pine plantations. Modifications often involve ditching and diking that alter hydrologic flows. 5) Maritime non-wetland forest typically is found on an inorganic substrate, and is the forest environment most likely to have been developed. 6) Miscellaneous depressional swamps and non-riverine hardwood swamps are isolated with poor drainage. They are less common than the other environments.

Sea-level influences

Pocosins to fringing marsh

Pocosins are by far the most abundant wetland type in coastal North Carolina with the next largest being wooded swamps. About 65% of wetlands in the counties surrounding Albemarle and Pamlico Sounds are pocosins (Bellis et al. 1975). Most pocosin peat lands are found on elevated interfluvial plateaus and thus mimic uplands in having outflows that can affect all connected wetlands and estuaries downstream. Pocosins are also located at low elevations along estuarine coastlines where they can maintain elevation with rising sea level (Brinson, 1991). Pocosins are characterized by being flooded during the winter and water logged during the remainder of the year. The dominant vegetations of pocosins are broadleaf, evergreen shrubs and pond pine (*Pinus serotina*). Pocosin soil is low in nutrients, and pocosins lack the abundance and diversity of wooded swamps (Copeland et al. 1983).

The migration of marshes over uplands in response to rising sea level in North Carolina will mostly involve marsh/pocosin transition zones, with the peat surface of pocosins becoming platforms for invading marsh community. The marsh commonly consists of brackish marsh dominated by *Juncus roemerianus* grading into fresher marsh dominated by *Cladium jamaicense* and *Panicum virgatum*. Inland from the marsh is a scrub zone where red cedar, wax myrtle, dying pines and pocosin species are found. This transition is caused at least partially by increased salinity. Thus the process of marshes invading pocosins and other freshwater wetlands occurs as a dynamic wetland continuum rather than a cluster of zones (Brinson, 1991).

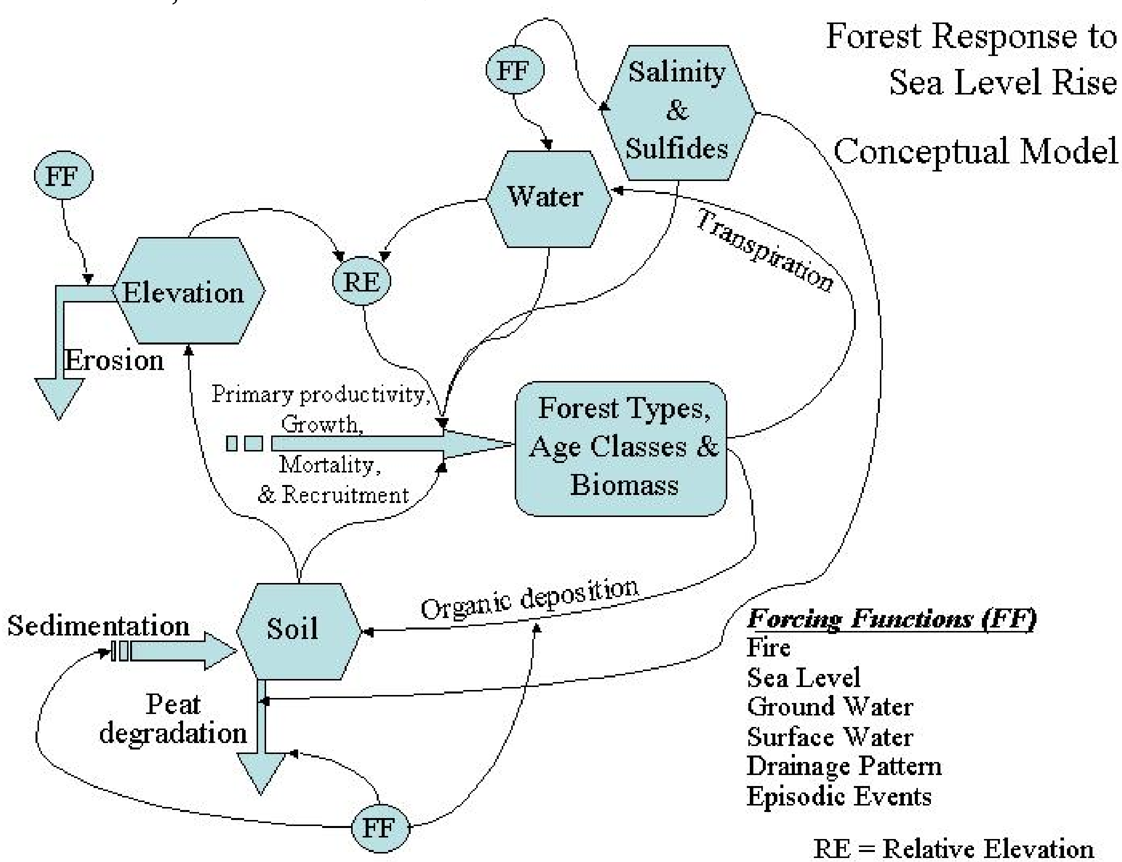
Pocosins to fringe swamps

Swamp forests are abundant in the Pamlico/Albemarle Sound estuary, constituting 30% of the mapped shoreline (Bellis et al., 1975). Swamp forests thrive in freshwater and cannot thrive in salinities greater than 5 ppt. Cypress-gum forests occur primarily along the embayed lateral estuaries throughout the region. The shoreline recedes as the gum and maple are drowned out by permanent flooding. The more flood tolerant cypress survives longer and is left standing as remnants at the edge of the swamp forest shoreline. If the cypress stand is dense, shoreline erosion is negligible (Copeland et al., 1983). In freshwater parts of the estuary, low salinity allows woody vegetation to persist along the shorelines making the transition much more subtle. This cypress fringe that develops along these non-tidal but sea-level-controlled wetlands is a complex of wind thrown trees, cypress knees, dead tree stumps and some aquatic plants. Shoreline erosion is necessary for the maintenance of this habitat, and its use as a shallow water habitat for fishes has not been documented. The conditions on the fringe wetlands are critical to the early life stages of finfish and shell fish (Brinson, 1991).

Modeling forest Changes

The response of a forest environment to sea level change depends on the interaction of a set of conditions (modeled as “state variables”) with a set of processes.   State variables include elevation, water level, vegetative community types, salinity, soil type, and land cover and land use history. These are conditions that could change in response to environmental forcing. The combination of elevation and water level are key factors determining relative water level or inundation frequency. These alter the vegetative community.   The salinity similarly determines the vegetative community based on mean and episodic events. Soil type determines what community may exist and the potential for loss of elevation by degradation. Finally, some communities have different characteristics depending on how they were previously used. For example, a recently abandoned field will have different characteristics than a mature forest. Also, areas that were drained for plantations may have different vegetation or water levels than expected based on the elevation.

The processes that drive the changes in the state variables include primary production, mortality, regeneration, organic deposition, transpiration, peat degradation, shore erosion, surface erosion, and sedimentation.



Conceptual ecosystem model for forest response to sea level rise.

Processes and Knowledge Gaps

Primary Production

Primary production determines vegetative health and stability. A complete failure of production, of course, leads to death. However, low production may impact elevation by reducing leaf litter inputs and reducing belowground biomass. Low primary production may also render trees more susceptible to disease and mortality from storms, increasing the effects of these stressors. Factors that influence primary production include salinity, inundation, soil type, soil chemistry, and nutrient availability. Currently we have a good understanding of the basic characteristics or niche space of trees and vegetative communities, as demonstrated in the vegetation associations for different environments. For example, brackish forested tidal swamps have cypress, black gum, and ash; while fresh tidal swamps have cypress, gum tupelo, and red maple. We do not have a good understanding of the thresholds of tolerance or understanding of the nutrient cycling. In particular, we lack information on soil sulfide impacts and inundation thresholds for mature forests.

Regeneration

Regeneration determines the long-term survival of the community. Even if the mature trees can tolerate the conditions, the community will ultimately cease to exist if regeneration does not occur. The key factors determining regeneration are salinity, inundation, soil chemistry (especially sulfide toxicity), nutrient availability, and herbivory. Currently salinity and inundation impacts are well documented for first-year seedlings of certain tree species. Changes in seedling response with age are not well known, nor are the impacts of sulfides.

Organic Deposition

The organic deposition includes leaf litter and belowground biomass and determines both the amount of peat and the elevation of the peat (through root biomass). This is forced by primary production. Extensive data sets exist on aboveground deposition, through various leaf litter studies. Data on belowground biomass are lacking.

Transpiration

Transpiration will influence the water level in the system. This will particularly influence groundwater, which can also alter inundation frequencies. It is determined by vegetation type and primary production, which are, in turn, influenced by other factors. Transpiration is well measured and modeled with very good documentation.

Peat degradation

Peat degradation leads to loss of elevation, which increases the frequency of inundation. Processes contributing to peat degradation include fire, which is most dangerous under severe drought, sulfate-driven degradation, and water levels and flooding. There are insufficient data for rates of degradation, particularly that driven by sulfate reduction.

Shore erosion

Shore erosion by waves or currents results in a direct and immediate impact on the forest environment. Erosion is driven by waves, currents, disturbances, and boats. There are good models for determining waves for given wind conditions and bathymetry.

Surface erosion

Surface erosion occurs as a result of surface water flow during precipitation or severe flooding events. This is probably a relatively unimportant and highly localized process in these forested environments.

Sedimentation

Deposits of sediment can occur along some river banks, leading to levees causing an increase in elevation. Inundation frequency, proximity to source material, and concentration at the source are the dominant factors determining sedimentation. However, most sediments deposit with a few meters of the source water, making this a relatively unimportant process in forested environments.

Conclusions and recommendations:

The workgroup established the following set of priorities for obtaining information necessary to produce a predictive model of forest change in the face of rising sea level. As inundation is a driving factor in determining primary production and regeneration, understanding elevation and water level are critical. This also involves soil type, as peats are more likely to be lost, and are most subject to degradation in the presence of sulfates supplied by sea water. Data contributing to the ability to predict salinity and sulfate levels at appropriate spatial scales and fairly fine temporal scales is a high priority, as this affects forest regeneration and peat degradation. All data must be in a computer friendly format in order to be linked to modeling effort.

Conclusion: The model must include a good soil map because different soils will respond to sea-level rise differently, potentially altering elevation and impacts of sea-level rise. Peat soils are more likely to be lost due to sulfate in sea water, resulting in decreased elevation. Furthermore, land-use practices can change soil properties, affecting their response to sea-level rise.
Recommendation: Update soil maps linked to vegetation, land use, and elevation.

Conclusion: The model will require an explicit characterization of how various communities relate to different flooding regimes and how those flooding regimes are related to elevation. Dramatic community changes may occur over an elevation range of as little as 10 cm.

Recommendation: Survey elevations of boundaries between critical habitats. Obtain water levels and historic inundation levels. This should link to a regional hydrologic model with feedback from change in land elevation.

Conclusion: Because vegetation and peat degradation respond to soil salinity, sulfate, and/or sulfide concentration, and because frequency, duration, and level (concentration) of exposure produce different effects, the model must be capable of predicting (either in a deterministic or probabilistic manner) peak daily salinity levels across the landscape.
Recommendation: Build a model that predicts variation in peak daily salinity across the landscape. Salinity of river and ground water must be linked to surface salinity through the model.

Conclusion: The model will require better quantitative data on the response of plant production to salinity, inundation and sulfide exposure than are currently available.
Recommendation: Obtain field relationships with salinity, inundation, and sulfide for episodic effects (death) and cumulative effects, especially on belowground biomass for elevation. Changes in the response of primary production of trees with age are not known.

Conclusion: The model will require better relationships between tree regeneration and exposure to salinity, sulfide, and inundation than are currently available. Most current data exist only for first-year seedlings, and most current data are derived from laboratory studies that do not always translate well to field conditions.
Recommendation: Obtain age-related field relationships between regeneration success and salinity, inundation, sulfide. Studies should include reciprocal planting and must address and/or control herbivory.

Conclusion: Too little is known about the effects of sulfate on peat degradation, and too little is known about effects of sea water on belowground biomass production to quantitatively predict the effects of saltwater intrusions on elevation changes. Nutrient availability may effect both organic deposition and degradation.
Recommendation: Obtain data on impact of sulfates on peat degradation.. Obtain field relationships for cumulative effects of seawater exposure on belowground biomass production. Account for effects of nutrient availability in both.

IV. Habitat Use

The Habitat Use workgroup focused on processes important to ecosystems in estuarine and coastal habitats that were not covered extensively in the wetlands and forests groups. In order to assess the ecological impacts of sea level rise, it will be necessary to develop predictions of habitat extent and quality for several habitats deemed by the group as “strategic” for the North Carolina coast. These include

1. nursery and spawning areas for anadromous fish and offshore and estuarine spawners;

2. refugia, larval staging areas, and migration corridors in the nearshore ocean;
3. oyster reefs;
4. seagrass and SAV beds;
5. soft-bottom benthic habitats, especially in the intertidal;
6. pelagic habitats in estuaries and coastal lagoons; and
7. shore-line areas and dredge spoil islands that are habitats for waterfowl and shorebirds.

Many important habitats are in shallow water (SAV, shell bottoms, wetlands) and would be affected by sea level rise, especially if there is a major breach/loss of the Outer Banks, converting the Albemarle-Pamlico system into high salinity bays of the ocean. Maps of current habitat locations and scenarios of what may happen to these habitats would be very useful.

The Pamlico Sound is fresh to mesohaline and the Albemarle Sound is mostly fresh with occasional oligohaline occurrences. The phytoplankton community in APES is dominated by diatoms, dinoflagellates and blue green algae. Phytoplankton blooms attracted attention since the *Pfiesteria* outbreaks of the early 1990's particularly in the Currituck Sound. More recently, the area has better fish habitat not only in the Sounds but also in the upper partitions of the tributaries (personal communication M. Brinson). Submerged aquatic vegetation (SAV) typically plays a large role in primary production and is discussed in more detail elsewhere in this report by an ad-hoc group. In general there is a seasonal pattern of abundance and biomass where a summer increase in productivity results in the largest biomass in early fall and the lowest in early spring (Davis and Brinson, 1976). Nursery areas are usually nearshore and shallow where they support high densities of juveniles of fish and crustaceans during their first growing season (Copeland et al.1983). Food chains and trophic structure in the APES have not been extensively studied but oligohaline estuaries generally have abbreviated food chains (Copeland, 1981). No extensive studies have been conducted to assess phytoplankton, zooplankton and benthic communities. However as is typical for an oligohaline estuary, the benthic community is dominated by Rangia clams (Copeland et al., 1983).

Four major populations characterize the fisheries of APES. Anadromous fish, primarily blueback herring, alewife, striped bass, and shad making spawning runs up the estuaries during the spring. These fish switch their food preference as they grow such as a zooplankton diet in the post-larval stage, to a more diversified of benthos in the juvenile stage to fish and benthos as adults (Copeland, 1983). Indigenous catfish, white perch and yellow perch make a large part of the winter biomass. Based on current data and conditions, blue crabs are residents of Albemarle Sound. Spot and croaker utilize Albemarle Sound just as they do Pamlico Sound, but salinity limits how far west they occur. Based on harvest data, American eel stocks are at low levels at present. As there is very little data on them, the official stock status is "unknown".

Oysters are truly a keystone species since they create habitat for other species and filter the water column in addition to their own life history functions. Oysters in the APES area are officially in a "concern" status, which means levels are depressed Over-fishing occurred100 years ago by major dredging efforts in the late 1800s - early 1900s and stocks have never recovered. The oyster parasite Dermo (*Perkinsus marinus)* hit hard starting about 1987 (although very little MSX, *Haplosporidium nelsoni,* has been noted). The oysters die late in their second summer, just before reaching the minimum legal harvest size of 3". There are various cultch planting programs, but it is much too little in volume. And as harvests decrease, there is less cultch available for planting -- a downward spiral that will hopefully change using marl (limestone rock), but the state is quite limited in their planting capability (personal communication, Mike Street).

It can be argued that Atlantic menhaden are also a keystone species since they filter the water column, export energy from estuarine nursery areas to the ocean, and are an important prey species for many other finfish, sea birds, and marine mammals. The APES area is used by at least 17 species of over-wintering waterfowl. Water fowl use is largely limited to the river tributaries rather than the open sound (Copeland, 1983).

NC manages well over 100 species of finfish, crustaceans, and mollusks that are harvested by commercial and sporty fishermen in coastal North Carolina. Most are estuarine-dependent. The most important species (considering volume, value, effort) include blue crab, southern flounder, summer flounder, Atlantic menhaden, Atlantic croaker, shrimp (brown, white, pink), hard clam, bluefish, weakfish, snappers and groupers, king and Spanish mackerels, spot, sharks, tunas, striped mullet, sea and bay scallops, striped bass, kingfishes, and dolphins, among others. State Fishery Management Plans (FMPs) are in place (or in preparation) for oysters, hard clams, river herring, red drum, blue crab, southern flounder, striped mullet, and shrimps. North Carolina also participates in interstate FMPs with the Atlantic States Fishery Management Council and regional councils under the Atlantic Coastal Fisheries Cooperative Management Act and Magnuson-Stevens Act. The managed species/stocks utilize all the available habitats: water column, submerged aquatic vegetation (SAV), shell bottoms, wetlands, soft bottoms, and ocean hard bottoms. While some species are clearly dependent on a specific habitat type (snappers and groupers on ocean hard bottoms), most use different habitats throughout their lives. "Association" is probably more accurate than "dependence." (personal communication, Mike Street).

Knowledge Gaps

Ultimately, predictions should provide indications of the landscape scale of ecological interactions, and how the mix of habitats on different spatial scales will change due to SLR. Edge effects will be very important, and transition zones between habitats will likely be the first to see effects of SLR. The translation of habitat transitions to resources lost or gained is poorly known and greatly needed, as it is the crux of many management programs and permitting issues.

Predictive capability will come about only through an understanding of the biological responses to circulation changes resulting from SLR. It will be necessary to have 3-D models of circulation changes in order to understand stratification conditions important for primary productivity and hypoxic events. While a full 3-D model of the entire domain may be unrealistic, perhaps representative areas in the 2-D model could be identified for expansion into 3-D. Biological models must be coupled to circulation and stratification models in order to understand larval transport and population dynamics. It will be crucial to match the scales of physical and biological models, and to identify population bottlenecks and threshold effects that can change system dynamics. While the modeling capability is in place for most of these efforts, it remains a challenge to link physics to animals at appropriate scales.

Before proceeding with modeling and prediction, several information gaps need to be filled. For instance, underlying geology and human occupation and defense of shoreline areas are crucial variables in understanding susceptibility to erosion and the ability of an area to change from one habitat type to another. In North Carolina, the baseline geology is mostly known, and land cover/land use is fairly well-known for currently defended shorelines and land use planning areas. However, the intertidal is not mapped, and intertidal extent and elevation will be critical to make elevation predictions. A digitized map or database of current shoreline hardening/protection is needed, along with Lidar surveys for intertidal heights and areal extent.

In specific habitats, some information exists, but it may not be sufficient for prediction. Nursery areas are fairly well-known for most fish species. SAV dynamics, distribution, and physiology have been studied in high-salinity environments, although low-salinity environments are less well-known. The habitat use of most birds is known, as is general knowledge of benthic dynamics. Questions remain about the effects of particular habitat changes on habitat functionality, the relative rate of habitat change vs. resource impacts, the relationship between habitat area and its function/production, and the overall influence of SLR at the local habitat level.

It is recognized that SLR will occur within the context of co-variables, which will affect organisms and their ability to exploit habitats. For example, temperature and salinity changes and altered storm frequencies may affect species' ranges and invasions of non-native species that lead to community changes. Groundwater changes due to SLR and precipitation change will affect nutrient delivery, primary productivity, and oxygen relationships. Pollutant sequestration in sediments and their release due to changes in erosion and wave dynamics can lead to health and ecosystem effects. Far-field effects on systems outside North Carolina can lead to invasions of non-native species and altered migration routes, with implications for species distributions and interactions in the North Carolina area.

Finally, the workgroup realized that some species may be of special concern because of their endangered or threatened status. Examples of such species are manatees, bottlenose dolphins, sea turtles, diamondback terrapins, piping plovers, black skimmers, black oystercatchers, least terns, coral snakes, sundews, pitcher plants, Atlantic sturgeon, and various rare plant communities, lizards, salamanders, and invertebrates.

Processes:

The processes that must be well understood in order to predict changes in habitat use due to SLR include:

1.) a three dimensional circulation of the waters of the APES system including storm surges.
2.) biological response to circulation of water including salinity, temperature, larval distribution, wetland gradient, hypoxia, nutrients, and phytoplankton.
3.) geology and human occupation effect on shoreline
4.) habitat extent and geometry, connectivity and quality for strategic habitats, both benthic and pelagic. Nursery areas, edge of habitats, soft bottom benthic habitats especially intertidal, refugia, spawning areas, and migration corridors are of special importance.
5.) Groundwater changes due to SLR
6.) Pollution sequestration in sediment and changes due to SLR
7.) Far-field effects that may result in invasion of non-natives.

Conclusions and Recommendations:

Conclusion: The biological response to circulation changes due to SLR should be modeled to represent stratification, water temperature, salinity, larval distribution, wetland gradients and hypoxic events. The model(s) must have matching scales of the physical and biological models and include population bottlenecks and threshold effects.
Recommendation: the current 2-D model needs to be expanded to 3-D for representative areas in a few selected tributaries and inlets. Biological modeling capacity in place needs to be linked to 3-D physical model.

Conclusion: The geology and human alterations of shoreline affect susceptibility to erosion and the suitability as habitat. The baseline geology is known as well as the land cover and use.
Recommendation: Database or digitized map of current shoreline hardening or protection. Intertidal area extent and elevation projections needed.

Conclusion: Edge and shoreline effects are important in determining the mix of habitats on different spatial scales, watershed functions, and habitat for waterfowl and shorebirds. Some processes of watershed function are understood at the landscape level, but there is a need to determine how SLR will influence edge effects on a local scale. How waterfowl populations react to changes in shoreline area and position is unclear.
Recommendation: Field studies to elucidate relationships between water level changes and habitat edge function for key species (defined with the help of resource managers/conservationists); coordinated physical and biological modeling to predict edge and shoreline changes with SLR

Conclusion: For species using estuarine habitat such as anadromous and off-shore and estuarine spawners, nursery areas are well known for most species. Spawning areas are known for a few species. Cumulative impacts of multiple stressors on nursery and

spawning areas are not well known. It is not known what the effects on growth and mortality will be resulting from a loss of functionality with habitat shift due to SLR.
Recommendation: Data mining to synthesize information re. spawning and nursery habitats in the region for key species (defined with the help of resource managers). Use this data in coordinated biological-physical modeling of multiple effects. Where little or no data exists for certain species, field studies to evaluate spawning and nursery function of estuarine habitats, and relative functionality (reproductive, growth, mortality) of different habitats.

Conclusion: Spawning and staging areas for larvae in nearshore ocean, refugia and migration corridors are known for some species. The linkages between fish and habitat and rate of habitat change and the effects on resources are poorly known.
Recommendation: Data mining for information re. use of nearshore habitats by key species (defined with the help of resource managers). Field studies to understand relationships between nearshore habitats and resource impacts. Use this data in coordinated biological-physical modeling.

Conclusion: Restored reefs and oyster reef locations and habitat function are mostly known. Unknown is the relationship between reef area and the function and production of important species.
Recommendation: Data mining for information on species dependent upon oyster reefs. Field studies to examine links between reef area and reef habitat function. Coupled modeling to describe and predict relationships.

Conclusion: Soft bottom benthic habitats, especially intertidal, are only very generally known. Changes in benthic dynamics and sedimentation are less well known in relation to SLR. The nature of sediment delivery is unknown as well as areal changes.
Recommendation: Data mining for information on species dependent upon soft bottom areas (intertidal and subtidal). Field studies to examine sedimentation and benthic dynamics. Coupled modeling to describe and predict relationships.

Group Integration

The breakout groups met for a discussion of the commonalities of needs and concerns. Much discussion focused on how to deal with the barrier islands. The barrier islands cannot be ignored because changes in their presence and conformation are likely. They will dominate processes affecting the ecosystems landward from the islands. The conclusion was to model several scenarios with different barrier island conformations There should be no prediction on how barrier island conformation will change.

Concerns were raised as to whether the LIDAR would give sufficient resolution in elevation to predict effects of sea-level rise over the course of 50 years. Both the marsh breakout group and the forest breakout group called for elevation data with a vertical resolution of 10 cm. In zones affected by sea level, a change in elevation of 10 cm produces very notable changes in plant community. Furthermore, 50 years of sea-level rise in the P/A region (0.6 ft/century), is equivalent to a rise of ca. 15 cm which is less than the vertical resolution of LIDAR. The model was intended to predict consequences of sea-level rise over this time span. Perhaps, LIDAR could identify a zone ~1-2 m in height across which more precise elevation data could be obtained.

There was some discussion of whether the model needed to include the entire sound, instead of just the current project area (Fig. 1). It seemed obvious that for processes the Physical processes Breakout group and habitat use breakout group were concerned with, it did need to encompass the entire sound. There was no discussion on whether the marsh and forests needed to be modeled through a more extensive area. Could a model be made that tested the sensitivity of the estuarine and sound systems to feedbacks from the forest and marsh to determine whether these different components needed to be modeled over the same spatial extent?

What should the spatial scale of the model be? This was brought up at the very end of the last plenary session, and wasn't really resolved. The marsh group suggested a scale of 5 m. Others suggested that the model was not intended to predict changes even on the scale of individual property lots. A 5-m scale is a manageable experimental set-up. Also, effects of 50 years of sea-level rise on steeper slopes will only be detectable if you look at a fairly narrow band of land area. However, would such changes won't be important to managers? In retrospect, perhaps the spatial scale should be linked to a scale that managers are interested in.

How will the model handle include storm events, droughts, floods, fires (especially in peat) with sea-level rise? There is a need for a probabilistic approach to address these issues.

SAV group summary- post hoc

How the predicted future sea level rise will change submerged aquatic vegetation (SAV) is an important process for coastal managers to understand. This is because the present distribution of SAV has unequivocally been demonstrated to be driven by water depth, water column optical properties (light reaching the plants), nutrient loading, salinity, exposure to waves and currents, biological disturbance and fishing practices, and in particular, vulnerability to extreme events. Because SLR is anticipated to strongly influence freshwater inflow, topology, exposure and faunal regimes, the physico-chemical changes wrought by SLR on the coastal landscape are expected to have profound effects on the abundance and distribution of SAV in North Carolina. In turn, substantive changes in the SAV community will strongly shape the physical integrity of the coastline. Because of their closer ties to fisheries than salt marsh, changes in SAV will affect the fisheries of the future.

SAV is a critical component of the North Carolina estuarine community. SAV functions to stabilize shorelines by binding shallow underwater sediment with their roots and rhizomes in shallow offshore regions, trapping suspended sediment and baffling waves and currents SAV modifies sediment quantity and quality, decreasing underwater erosion and shoreline structure; it is therefore an important part of the structural integrity of the North Carolina's nearshore environment (for a more thorough discussion of the role of seagrasses in nearshore sedimentary processes, see Fonseca, 1996). SAV also functions as important habitat for many fish and shellfish, including some of our most valuable commercial and recreational species and promotes the overall biodiversity of floral and faunal species in shallow water.

General Description of North Carolina SAV

The most recent estimate for estuarine SAV in North Carolina is approximately 200,000 acres, about equal to the area of salt marsh in the system, or about 8.5% of the estuarine bottom in North Carolina (based on salinity maps from NOAA). SAV habitat is dominated by one or more species of submerged rooted vascular plants or macroalgae depending on the time of year. The distribution and species composition of SAV in any of the sub-basins of coastal North Carolina estuaries can be broken up by salinity and by habitat.

Non-tidal fresh water SAV are not within the scope of this study, but many non-tidal freshwater species also found in tidal fresh water. Little is known about tidal freshwater in a geographic context. Tidal freshwater SAV is mainly found in northern Pamlico Sound. Many areas may be undergoing significant species shift as a result of introduced taxa. For example, Eurasian milfoil (*Myriophyllum spicatum*) can out compete native freshwater eelgrass like *Valisinaria* species. These habitats are therefore conflicted between the need to preserve habitat complexity and State programs that actively eradicate invasive species in order to reduce biological oxygen demand (BOD) and improve navigation and recreation. Tidal freshwater SAV species include Redhead Grass (*Potamogeton perfoliatus*), Sago Pondweed (*Stuckenia pectinata*), Common Waterweed (Elodea canadensis), Hydrilla (Hydrilla verticillata), and Pondweeds (*Potamogeton perfoliatus*). Tidal brackish (polyhaline) species in this group include the fresh water species already mentioned. In addition, significant habitat is dominated by and Widgeon Grass (*Ruppia maritima*) which is euryhaline. Tidal saltwater species include three main species: eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and Widgeon Grass. Most significantly, North Carolina is the area of overlap of the temperate *Z. marina* and the sub tropical *H. wrightii.* Because of a bi-modal seasonal abundance of these two species (*Z. marina* waxes in colder months and wanes in the summer when *H. wrightii* is proliferating), this overlap provides a unique, nearly year-round abundance of seagrass that is crucial for the sustained high levels of estuarine production for which North Carolina is known. Any SLR-associated effects on this bi-modal strategy may strongly influence ecological functions and fishery landings. Some of the distribution and seasonal patterns are influenced by physical settings, and depending on season, may be influenced by reproductive strategies. Some species rely almost exclusively on sexual reproduction while others either maintain their populations by vegetative growth or a combination of sexual and vegetative reproduction.

Like marshes, SAV beds can be generally categorized into four general habitat types, within which there are a wide variety of landscape patterns, from continuous to patchy cover.

1) *Mainland fringe beds.* These encircle the main shore where the shoreline rapidly drops below the compensation depth for SAV existence. Most of the tidal brackish SAV habitat is found in these beds.

2) *Back Barrier flat and open water shoals.* These grow on relic, broad over wash lobes and sandbars that provide prime habitat for most of the marine seagrass acreage in North Carolina. These flats are very shallow and with variable organic matter content depending of hydrodynamic condition while intermingling with salt marsh they provide the broadest range of habitat settings, supporting a wide variety of productive fish and shellfish harvest areas.

3) *Riverine communities*. Generally fringing communities, strongly constrained by lowered optical water quality and low salinities, many of these beds are highly seasonal and are composed of non-seagrass species.

4) *Embayment Beds.* Partially enclosed by marsh or shoreline, these beds are usually extensive and nearly unbroken in cover (as compared to the open water, dune-like beds that populate much of the exposed estuarine floor). These beds typically have very high organic and silt clay contents and high infaunal abundance (but lower belowground biomass) than the dune-like habitats.

<u>Knowledge Gaps</u>

Although SAV is such a critical ecosystem estuarine and coastal ocean health, there are many gaps in our knowledge that is needed for proper management. These gaps include:

- Understanding spatial pattern of landscape units and their interaction is critical both in terms of sediment stabilization and habitat function
- Forecasting consequences of disturbance and water quality changes on shorelines and how shoreline changes will affect SAV distribution and abundance.
- Forecasting the interplay of physical exposure (disturbance or extreme events), tidal amplitude, and optical water quality on geographic distribution and landscape composition.
- Forecasting the affects of SLR on reproduction and dispersal of SAV under different environmental scenarios.

<u>Processes critical to Vertical Change and Horizontal Extent of SAV</u>

The physical drivers that affect SAV's vertical growth and horizontal extent are generally the same. Tidal range varies throughout NC from spring ranges of over four feet on the northern outer North Carolina coast, to spring ranges nearly six feet near the southern end of the outer banks to basically no astronomical tide in the Albemarle- Pamlico Sound. SAV are often strongly influenced by extreme tidal events (both low and high) due to astronomic factors and weather related phenomena (e.g., strong northeasters). During extreme low tide levels, SAV may be exposed to the air, heated, desiccated and illuminated by excessive amounts of UV light. When the tide level is very high, the seaward edge of the SAV bed may be too deep to receive adequate light for photosynthesis. In addition, extremes in tidal currents can shape the SAV pattern and distribution through erosion, accretion and sediment movement. When exposure to waves (particularly extreme events such as hurricanes) are too strong, SAV cannot maintain persistent populations; beds will colonize and spread, forming the classic 'leopard skin pattern', only to be severely eroded or eradicated during additional tropical storms or northeasters. Waves from prevailing winds and storm winds, as well as availability of suitable substrate can alter the physical and horizontal attributes of SAV. Wave effects include the frequency, intensity and duration of storm events as well as the path of storms, and space availability affects the dispersal capacities of SAV. Not only with tides, waves and extreme storm events affect SAV directly, they will also affect SAV indirectly by disturbing the shoreline. Eroding shorelines and disintegrating salt marshes will result in large quantities of suspended sediments and organic matter that will negatively affect the optical water quality.

Optical water quality controls the vertical accretion and horizontal extent of SAV because it affects the light quantity and quality. State boundaries are determined by the upper emersion boundary and the subtidal boundary. If the water column is clear photosynthetically active radiation will penetrated deeper and seagrass can grow to greater depths and extend their horizontal distribution. As the water column becomes more turbid with increased sediment load, color or plankton, the depth to which SAV grows becomes proportionally limited. Because different seagrass species have different compensation depths and air exposure (and UV tolerance), changes in water column optics and/or the vertical datum of the estuarine floor can lead to dramatic changes in seagrass species. Concomitant changes in local fauna can be expected both as the result of changes in seagrass species (and seasonal affinity) as well as by the environmental changes themselves – a combination of effects that cannot be forecast without substantial knowledge of the systems. Excess nutrient loading accompanying storms and the rate and volumes of upland loadings has been shown to increase algal abundance to the detriment of SAV. Similarly, processes affecting horizontal state changes include salinity and temperature that limit the physiology of SAV species and has been shown to control their distribution. In addition, natural biological disturbance as well as physical factors such as habitat-destroying fishing practices and invasive species.

Conclusions and Recommendations:

Conclusion: SAV production information for various species is adequate for prediction and modeling.

Recommendation: Optical water quality model needs to be calibrated to apply to various water bodies

Conclusion: Bathymetric spatial resolution is inadequate in critical areas.

Recommendation: A high resolution hydrographic survey in critical areas where SAV is known to occur or forecasted to occur.

Conclusion: Knowledge of the population dynamics, dispersal strategies and recolonization rates for some species is limited.

Recommendation: Need for experiments, surveys and literature review to estimate rates and model population dynamics of all species.

Conclusion: There is not enough data on the effect of episodic events on SAV

Recommendation: Long term data collection after episodic events of varying degrees of severity.

Conclusion: Historic shoreline comparison to current shoreline is necessary to determine the affect of historic sea level rise on SAV beds.

Recommendation: Comparison is needed of historic charts to current shoreline

Conclusion: Model will need to understand the changes in seagrass species due to physical and ecological changes.
Recommendation: Greenhouse experiments on the growth and competition among SAV under different habitat and physical driver treatments.

Conclusion: Changes in fish species can be modeled to indicate changes in SAV health and extent.

Recommendation: A Field survey is needed using stratified sampling of SAV communities and then a comparative analysis to fishery organisms.

Summary

The impacts of sea level rise will vary by location and will depend on a range of biophysical characteristics and socioeconomic factors, including human response. The primary impacts of sea level rise are physical changes to the environment. These changes, in turn affect human uses. The most serious physical impacts of sea level rise on coastal lowlands are inundation and displacement of wetlands and lowlands, coastal erosion, increased vulnerability to coastal storm damage and flooding, and salinization of surface water and ground water. Analysis of existing sea level rise impacts literature suggests that forward looking policies at the local, state and federal level could serve-to mitigate the effects of sea level rise. Information about the implications of sea level rise is needed in order to best to prepare for and adapt to sea level rise. Shoreline protection and land-use decisions are mostly made at the local level or on a parcel-specific basis; so maps that show the site-specific implications are most important.

The goal of the EESLR Program is to provide meaningful ecological data embedded in sub-models that can be integrated with a coastal flooding model. These combined models will predict the ecological effects of projected sea level rise including landscape responses relevant to critical natural resources. The final result will be ecological maps, models, data and understanding to aide coastal managers to plan long-term response to sea level rise as well as day to day decisions. These models and maps will indicate to managers which areas are the most vulnerable and in most need of immediate action. By helping managers and planners decide which commercial activities and land use practices should be encouraged or enforced to mitigate the impacts, protection of ecologically and economically important habitats and species can occur.

Acknowledgements:
This program has benefited from the advice of a Technical Advisory Committee consisting of Dr. Kurt Hess, NOAA Office of Coast Survey, Dr. Rick Stumpf, NOAA Center for Coastal Monitoring and Assessment, Guy Stefanski, North Carolina Division of Coastal Management, and Dr. Denise Reed, University of New Orleans. Dr. Mark Fonseca and Dr. Jud Kenworthy of the NOAA Center for Coastal Fisheries Habitat Research contributed the *post hoc* SAV section. Special thanks to Kim Williams, Mark Brinson, Mike Street and Linda Blum for their invaluable advice and for reviewing sections of this report.

Biographies and contact information for workshop participants are available from Carol Auer.

Questions about this document should be addressed to

Carol Auer (carol.auer@noaa.gov)
NOAA National Ocean Service
CSCOR Coastal Ocean Program
N/SCI2
SSMC4 Room 8336
1305 East West Highway
Silver Spring, Maryland 20910
301-713-3338X164
Fax- 301-713-4044

References

Bellis, V., M.P. O'Connor, and S.R. Riggs. 1975. Estuarine Shoreline erosion in the Albemarle-P Region of NC. University of NC Sea Grant College Program, Raleigh. 75-29:1-67.

Bird Eric C.F .1993. Submerging coasts; The effects of Rising Sea level on Coastal environments.

Brinson, M.M., H.D. Bradshaw, and M.N. Jones. 1985. Transitions in forested wetlands along gradients of salinity and hydro-period. Journal of the Elisha Mitchell Scientific Society 101:76-94.

Brinson, M.M. 1991. Landscape properties of pocosins and associated wetlands. Wetlands 11:441-465.

Brinson, M.M., R.R. Christian, and L.K. Blum. 1995. Multiple states in the sea-level induced transition from terrestrial forest to estuary. Estuaries 18:648-659.

Clark, James S. et al. 2001. Ecological forecasts: an emerging imperative. Science, v. 293 no5530 (July 27 2001) p. 657-60.

Copeland, B.J. et al 1983. The Ecology of Albemarle Sound, North Carolina: An Estuarine Profile. U.S. Fish and Wildlfe Service, Division of Biological Services, Washington, D.C. FWS/OBS-83/01. 68pp.

Davis, G.J. and M.M. Brinson. 1976. The submersed macrophytes of the Pamlico River estuary, North Carolina. Water Resource. Res. Inst . Univ. North Carolina, Rpt. No. 112, Raleigh. 202 pp.

Michener, W.K., E.R. Blood, K. L. Bildstein, Mark M. Brinson, and L.R. Gardner. 1997. Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. Ecological Applications 7(3):770-801.

Moorhead, K.K. and M.M. Brinson. 1995. Response of wetlands to rising sea level in the lower coastal plain of North Carolina. Ecological Applications 5:261-271.

Odum, W.E. et al. 1984. The Ecology of tidal freshwater marshes of the U.S. East Coast: a community profile. U.S. Fish and Wildlife Service FWS/OBS-83/17. 177pp.

Thomas, C. R. 2004. Salt marsh biogeochemistry and sediment organic matter accumulation. Department of Environmental Sciences, Univ. VA, Charlottesville, VA. PhD Dissertation. p. 167.)

Appendix I: Tables from Breakout Groups
Physical Processes Break Out Group
Table 1a

Process/Variable	Rational	Nature of current knowledge	Sufficiency for prediction
Tides, astronomical	Persistent process, determines morphology, wetland type and distribution; nutrient, salt, and biota exchange	Locally good, regionally lacking	Adequate
Tides, wind	"	"	"
Atmospheric processes (e.g., coastal front, tropical and extra-trop. cyclones, evapotranspiration, precipitation)	Episodic and seasonal process, determines morphology, wetland and upland vegetation type and distribution; nutrient, salt, and biotic properties	"	Inadequate, especially for inundation
Storm surge	Episodic process, determines erosion and morphology, wetland and upland vegetation type and distribution; delivery of nutrient, salt, and biota	lacking	Fair
Hydrology of land and marshes (surface and subsurface); tidally flooded ramp marshes (dendritic) and platform, irregularly flooded wetlands (ditched)	Residence time, material I/O and transport, upland habitat, wetland distribution and function, water column and benthic community structure and function	Lacking or patchy	Inadequate for high-resolution scales
Hydrology of estuaries and sounds	Residence time, material I/O and transport, upland habitat, wetland distribution and	Locally good except for open sound currents	Locally good

	function, water column and benthic community structure and function		
Salinity, temperature, turbidity	Stratification, chemistry, biogeochemical cycles, Salt water intrusion, bio-optical properties	variable	Locally good
Wind waves	Erosion, shoreline movement; sediment re-suspension, transport, and deposition; geomorphology, habitat type	No wave data in sounds	Wave prediction adequate, impacts not well known
Geologic framework (surface and subsurface geology) [variable]	Habitat type, shoreline and sediment type, erosion rates, barrier island inlet locations	Good general picture	Adequate for some case studies, not for prediction
Bathymetry, topography, Geomorphology [variable]	Drainage patterns, patterns of inundation, habitat type	Good for topography, not so good for bathymetry, poor in near-shore and inter-tidal areas	Good for topography, not so good for bathymetry, poor in near-shore and inter-tidal areas
Sedimentation within wetlands, tide flats, estuarine basins, perimeter platforms, shorelines, scarp marsh edges	Maintenance of wetlands and channels, sediment balance	Poorly known	Poor
Human impacts and modifications	Erosion control structures, ditches, wetland disturbance, changes in runoff and land cover, roads and dikes, spoil banks, beach stabilization	Poor	Poor, or incomplete

Physical Processes Breakout Groups Table 2a

Process/Variable	Sufficiency for pred	Approach	Time frame	Data for validation
Tides, astronomical	Yes			
Tides, wind	Yes			
Atmospheric processes (e.g., coastal front, tropical and extra-trop. cyclones, evapotranspiration, precipitation)	Yes			
Storm surge	Yes			
Hydrology of land and marshes (surface and subsurface	No	1. Flow through marshes 2. Subsurface flow from land	1. 3 yr field study 2. 3 yr field study	
Hydrology of estuaries and sounds	No	1. fluxes thru inlets 2. circulation, mixing throughout sounds	1. 2 yr field study 2. 2 yr min	
Salinity, temp, turbidity	No	1. fluxes thru inlets 2. mixing in sounds	Same as above, and simultaneously	
Wind waves	Yes			
Geologic framework (surface & subsurface geology)	No	1. Map surf and sub-surf geology in study area 2. map shoreline type and change	1. 2 yr (add to existing program) 2. 2 yr	
Bathymetry,	Yes, except	Measure intertidal and shallow water	1 yr lidar or field	

topography, Geomorphology	intertidal areas	depths/elevations	study	
Sedimentation	No	1.Study wave erosion on shorelines 2.Study supply of sediment to marshes 3.organic accretion	1 yr data analysis 1 yr data analysis 1 yr field study	
Human impacts and modifications	No	1. map protection structures 2. quantify fishing impacts on sedimentation 3. map human activity in landward migration zone	1.1yr field, remote sensing, and data analysis 2.1 yr study 3.1-yr field, remote sensing, data analysis	

Marsh Breakout Group Table 1b

Table 1b: Processes Controlling Vertical Accretion

Process/data		Rational	Approach	Suff. for Prediction
OM accumulation	Production	Source of OM	Lots above for all types, and published/available Little below for any type	
	Decomposition	Loss of OM	Little below for all types	Below no
	Bioturbation/Export	Loss of OM	Little known – salt marshes	No
Sedimentation	Deposition	Source of material – major control on vertical accretion	Little known – Juncus rate of change known –hypothesized pulsed events	No
Shallow Subsidence	Compaction	Critical control on elevation	Little known	No
	Ground water flux	Influence on elevation	nothing	No

Table 1b: Processes Effecting Horizontal State Change

Process/data	Rationale	Nature of Knowledge	Sufficiency for Prediction
Marsh Edge Erosion **-** Wave energy	Reduction of marsh area	Measured for Cape Hatteras & north/ others possible	Existing wave exposure model
Inundation regime	Controls state change	Don't know intensity/duration/type of the thresholds needed to initiate state	no

		change – depends in part on state (e.g. forest to high marsh) – what type of rules are needed to identify when state change will occur	
Salinity	Controls state change	Don’t know intensity/duration/type of the thresholds needed to initiate state change – depends in part on state (e.g. forest to high marsh) – what type of rules are needed to identify when state change will occur	No
Disturbance (fire, hurricane, floods, anthropogenic, herbivory, disease)	Controls state change	Don’t know intensity/duration/type of the thresholds needed to initiate state change – depends in part on state (e.g. forest to high marsh) – what type of rules are needed to identify when state change will occur	No
Invasive species	Controls state change from mudflat to marsh		

Marsh Breakout Groups Table 2 b

Process Controlling Vertical Accretion

Process/data	Sufficiency for Prediction	Approach	Time Frame
OM accumulation Production	Above yes Below no	Field exp. Techniques (e.g. marsh organs) Greenhouse exp. Data mining to provide context Modeling exercises to link above Use chronic and acute response Consider population adaptations Above should focus on communities dominated by Juncus And S alterflora in non-tidal brackish & tidal salt and brackish habitats	3 yrs min
OM accumulation Decomposition Biotubation/Export	Below no Below no		
Sedimentation Deposition	No	Multiple radioisotopes and pollen analysis to insure a variety of time scales (ideally should coordinate with compaction study as described below	1-2yr
Shallow Subsidence compaction	no	Survey marsh substrate BD profiles and use to estimate compaction with cohort modeling approach	1-2 yrs
Shallow Subsidence Ground water flux	No		

Processes controlling Horizontal Extent- State Change table 2b

Process/data	Sufficiency	Approach	Time

	for Prediction		Frame
Marsh Erosion- Wave energy	Existing wave Exposure model		
State Change	no	Probabilistic or deterministic modeling based on historic info, exp, and monitoring data- need for clear statement of uncertainity	3 yrs
Processes contributing to state change Competition	No	Harper white competition experiments (not in greenhouse)	2yrs
Inundation regime salinity	no	Appropriately controlled field/mesocosm exp. To determine physiologic tolerances/thresholds to support state change models. Must be done in the context of plants from NC (genetic variation) and soils	2 yrs
Disturbance (anthropogenic hyper-eutrophication, hurricanes, floods, acute herbivory, fire and disease	No	Exp. Of opportunity (proscribed burns, clear cutting,etc), field exp.; change analysis based on historical info	2yrs

Forest Breakout Group Product Table 1c

State Variables	**Rationale**	**Nature of Current Knowledge**	**Sufficiency for Prediction**
elevation	Critical for inundation	Data collected by lidar	Yes, where lidar is available Knowledge of forest/marsh bound needs 5 cm -10 cm in some areas
Soil	**Critical** Determines vegetation type and potential for elevation change	Soil maps	No, revise soil characteristics map to incorporate organic characteristics
Vegetative community type	Determines response of system	State, CCAP, NWI	Probably, but need ground truth in context of communities relevant to this study
salinity	Determines vegetative health	Inferred	No, need salinity on surface waters
Water level	Determines inundation, peat stability		No, need water level in forests
Landcover/use history	Create accurate soil maps	Aerial photos, old maps, reports, etc.	No, data has to be reduced

Process/forcing factors	**Rationale**	**Nature of Current Knowledge**	**Sufficiency for Prediction**
Primary production Salinity Inundation Soil (include sulfide toxicity) Nutrients	**Health; primary production and community drives quantity & form of organic deposition**	Good understanding of niche space. No knowledge of thresholds, individual or cumulative . Nutrient cycling not known.	No, need data, esp. on salinity, sulfide, inundation on thresholds for mature forests.
Regeneration Salinity Inundation Soil (including sulfide toxicity) Nutrients	Maintains forest	Documented for certain tree species. Studies mostly laboratory with 1-yr old seedlings. Age response not known.	Ok for salinity & inundation for seedlings. Sulfide not known. Need age response of seedlings.

		Thresholds at low salinity not known.	
Organic Deposition Primary production (above & below)	Peat production	Above ground: reams of data; below ground: wanting	Yes, above ground No, below ground
Transpiration Vegetation type Primary production Tidal inundation precipitation	Drives water level	Measured, modeled or documented for certain trees/habitats	Yes
Peat degradation Fire Sulfate (salinity surrogate) Groundwater Flooding	Elevation loss	Processes understood; rates no	No, insufficient rates especially on sulfate; Groundwater needs wells, may or may not be present.
Surface erosion Inundation (currents)	Important for other places		
Sedimentation Inundation frequency Runoff from farms Potential (source concentration and distance from source)	Important for other places		
Shore erosion Waves impinging on the shore Currents Disturbance Boats	Habitat loss	Good wave models	Defer to physical process group.

Forest Group Table 2c

Process/data	Sufficiency for Prediction	Approach	Time Frame
Soil (high)	No	Update soil map tied to veg/land cover and elevation	2 yrs
Elevation (high)	No	Surveys of critical habitat boundary	1 yr
Water level (high)	no	Need field data. Peak daily inundation over 50 years, requires feedback from change in land elevation.	3-5 yrs
Salinity (high)	No	Need field data with a model to link to river salinity with groundwater and rainfall. Need peak daily salinity, spatial and temporal over entire study time (50 years).	3-5 yrs
Vegetative community type (high)	Probably	Ground truth program for verification and correct characterization of communities based on existing (digital) maps	2 yr
Landcover/use history	No	(Vital for validation) reduction & digitizing existing data (photos, maps, reports); field component (tree and soil coring) for selected areas	2-3 yrs
Primary production (high priority)	No	Need field relationships with salinity, inundation & sulfide for episodic effects (e.g. death) and cumulative effects (esp. on below-ground biomass) for elevation.	3-5 yrs
Regeneration (high priority)		Need age related field relationships & lab studies with salinity, inundation, sulfide, including reciprocal planting. Must address/control herbivory	3-5 yrs
Degradation (moderate priority)		Need data on impact of sulfate on peat degradation, need rates of below ground degradation	2-3 yrs
Organic Deposition (moderate priority)		Need field relationships for cumulative effects (esp. on below-ground biomass) for elevation. Nutrient dynamics	2-3 yrs

Model product	Data Sufficiency for Prediction	Approach	Time Frame	Data requirements for model validation
Forest water levels	No (except USGS flood levels in developed areas)	Water level gages Cores identify frequency in tidal and riverine	2+ yrs	Comparison of high water to model (include specific storms)
Groundwater	No (some wells in	Wells	2+ yrs	Comparison of groundwater

levels	nearby areas)			levels to model results
Soil	No	Dated cores, %organic matter, bulk density	2 yrs	Historic model run against core data
Elevation	no	Cores for accretion, search for old surveys (eg. DOT), SET sites	2 yr (SET +10 yrs)	Model against historic data
Surface salinity	No	Instruments	2+ yrs	Comparison of salinities to model
Vegetative community	No	Old aerial photos, imagery, old maps, surveys, Major data mining digitizing Cores, pollen seeds (also, repeat remote sensing regularly)	2-3 yrs	Historic model runs against data
below-ground biomass	No	Biomass cores or screens Field manipulations	2-3 yrs	Modeled biomass against measured biomass
Regeneration	No	Field inventories related to elevation & hydrology; look at age structure; reciprocal planting study	3-5 yrs	Modeled against observed
Peat degradation	No	SETs in sulfide controlled field experiment Tie to below ground biomass	3-5 yrs	Modeled against observed
Organic deposition	No	Derived from SET and cores	3-5 yrs	Modeled against observed

Habitat Use Breakout Group Table 1d

Process/data	Rationale	Nature/Sufficiency of Current Knowledge	priority	Approach	Time frame
Biological response to circulation changes					
A. Circulation process model, Stratification conditions, Physical energy into system chng re. SLR **B. Biological models** coupled to or influenced by physical circulation, Matching scales of physical and biological models, popn bottlenecks, threshold effects	A. Determines water levels, temp salin, larval distribution, wetland gradation, hypoxic events, B. Larval trspt, popn dynamics	Not included in current 2-D model – representative areas for 3-D model? Modeling capability in place, Not well-known phys to fish linkages	Critical re. outer banks dynamics,	Go forth and model	~ 3 yrs
Geology/human occupation & defense of shoreline, shoreline type, Coastal mgmt methods in relation to SLR	Susceptibility to erosion, suitability of habitat	Baseline geology known, land cover/use well-known (but poorly managed) Known/mapped areas and defended shorelines, land use plans in place; FEMA data for hardened shoreline? Intertidal not mapped	imp mgmt issue, need to add to SLR model before inaccurate predictions used	Database/digitized map of current hardening/protection; need intertidal extent and elevation projections; LIDAR surveys; is geol sufficiently known?	~ 2 yrs for database for Bogue Sound, 3 - 5 for statewide?
Predictions (through modeling and data collection/experiments) of habitat extent and quality (geometry, prey resources, connectivity, etc.) for "**Strategic habitats**" benthic and pelagic	Landscape scale of ecological interactions, water and associated materials balance in watersheds, Edge effects, mix of habitats on diff spatial scales,	Difficult to get b/c of scale; don't know if SLR will give more or less edge; some processes re. watershed function generally understood e.g. water balance, but influence of SLR at local level not explored	Data collection can take place before models; need data now	Coordinated phys and biol. data collection, modeling	2 yrs for some well-studied spp and habitats, >5 yrs for others
	Nursery and spawning fcn of estuarine habitat (anadromous and offshore/estuarine spawners),	Nursery areas pretty well-known for most spp., cumulative impacts not well-known (multiple stressors) Some data available on spawning areas of particular spp., unknown effects of loss on functionality w/habitat shift, unknown relative functionality (growth, mortality) of habitats	Relevant coastwide; priority for NOAA	Coordinated phys and biol. data collection, modeling	

	Staging area for larvae in nearshore ocn, spawning areas, refugia, migration corridors	General info known for some spp, insufficient for prediction, Unknown linkages betw habitat and fish, rate of habitat change vs resource impacts		Coordinated phys and biol. data collection, modeling	
	Oyster reef restoration (Fisheries habitat, living bulkheads?, marsh protection?)	Some known re. reefs and habitat function, unknown relationship betw. reef area and function/production	Imp as structural type	Coordinated phys and biol. data collection, modeling	
	Seagrass/SAV distribution (Bird migration, feeding, survival; nursery habitats)	Know a lot about SAV distribution, dynamics, physiology/production in hig sal; poorly known low-sal macrophytes dynamics and distribution	Imp as structural type	Coordinated phys and biol. data collection, modeling	5 – 6 yrs for photography at current pace
	Soft-bottom benthic habitats (esp intertidal)	General knowledge, changes in benthic dynamics less known, rates of sedimentation compared to SLR, nature of sediment delivery unknown, areal chng in intertidal unknown		Coordinated phys and biol. data collection, modeling	
	Pelagic habitats, spp distribution and success, spawning areas	Need to know impacts of SLR on pelagic habitats		Coordinated phys and biol. data collection, modeling	
	Shoreline changes, dredgespoil islands, Habitat for waterfowl, shorebirds	Know habitat uses of birds, unknown reaction of shoreline to SLR		Coordinated phys and biol. data collection, modeling	
Co-variates: Temp changes, salinity, storm freq.	Range extensions, invasions, losses, community chng	Some knowledge			
Groundwater changes re. SLR	Nutrient delivery changes, Prim productivity, where chl max is, O2 relationships	Groundwater delivery to estuaries poorly known			
Pollutant sequestration in sediments, changes re. SLR	Release of pollutants, carbon, health and ecosystem effects	unknown			
Far-field effects	Invasions of non-natives, migrations	Life histories of imp spp known, need to know linkages betw far field effects and local impacts			

<u>Species of special concern list</u>
Manatees – Manatee/grass interactions
Bottlenose dolphins – calving and foraging
Turtles – turtle/seagrass interactions (link to barrier island dynamics and seagrass beds)
Terrapins – marsh dependency
Piping plovers – barrier island/overwash zones
Colonial seabirds – dependent on estuarine islands w/o predators for nesting, feeding in intertidal areas
Colonial waterbirds – range expansion into NC, nesting and overwintering - Black skimmers, least terns, black oystercatchers
Salt marsh birds (rails, bitterns) – habitat alterations
Coral snakes – habitat availability and connectivity
Sundews/pitcher plants, cypress, maritime forests – saltwater intrusion
Rare plant communities, estuarine forests

Glass lizards, salamanders
Atlantic sturgeon
Invertebrates (snails, butterflies/moths)

SAV Tables (after Workshop)

SAV Processes Controlling Vertical Accretion

Process/data	Rationale	Nature of Knowledge	Sufficiency for Prediction
Tidal effects	Physical and physiological disturbance effects on pattern and distribution	Poor	No
Optical Water quality	Photosynthetic limits on distribution in limited number of water bodies	Very good	Yes
Wave effects	Physical disturbance effects on pattern and distribution in marine areas	Very good	Yes
Space	Availability of substrate affects distribution	Poor	No

SAV Processes Effecting Horizontal State Change

Process/data	Rationale	Nature of Knowledge	Sufficiency for Prediction
Tidal effects	Physical and physiological disturbance effects on pattern and distribution	Poor	No
Optical Water quality	Photosynthetic limits on distribution in limited number of water bodies	Very good	Yes
Wave effects	Physical disturbance effects on pattern and distribution	Very good	Yes
Space	Availability of substrate effects distribution	Poor	No
Salinity	Photosynthetic limits on distribution	Good	Yes
Temperature	Photosynthetic limits on distribution	Good	Yes
Biol. Disturbance	Physical disturbance effects on pattern and distribution	Poor	Yes

SAV Process Controlling Vertical Accretion

Process/data	Sufficiency for Prediction	Approach	Time Frame
Production	Yes	Calibrate optical water quality model to apply to various water bodies	< 2r
Bathymetry	No – spatial resolution inadequate in critical areas	Data collection High resolution hydrographic survey in critical areas	<1yr
Regeneration rates	Yes – but limited data	Field and lab research Experiments and surveys to estimate regeneration rates	3 yrs
Effect of episodic events on SAV	Yes – but limited data	Long-term data collection	5+ yrs

Model product	Sufficiency for Prediction	Approach	Time Frame	Data requirements for model validation
Estuarine water levels	Sufficient (tidal gage stations)			Comparison of high water to model
Shoreline change	No	Comparing historic charts to current	<2 yrs	Shoreline comparison
Changes in seagrass species (sensitive to ecological change)	No	Greenhouse experiments	3 yrs	Growth and competition comparisons among SAV
Changes in fishery species	No	Field surveys of extant beds	3 yrs	Stratified sampling of SAV communities and comparative analysis of fishery organisms

Workshop Participants

Appendix II: Workshop Participants

Physical Processes

Hans Paerl
UNC- Institute of Marine Science
Moorehead City

Len Pietrafesa
NC State Raleigh

Bill Nuttle
Eco-hydrology
Ottawa, Ontario

Dick Park
Eco Modeling
Diamondhead MS

Dean Gesch
USGS EROS Data Center
Sioux Falls, SD

Chris Zervas
NOAA Silver Spring, MD

STANLEY R. RIGGS
East Carolina University
NC Science Panel on Coastal Hazards

Tom Jarrett
NC Science Panel on Coastal Hazards

John T. Wells
UNC Institute of Marine Sciences
Morehead City
NC Science Panel on Coastal Hazards

Spencer Rogers
NC Sea Grant
NC Science Panel on Coastal Hazards

Walter Barnhardt
University of North Carolina
Chapel Hill
NC Science Panel on Coastal Hazards

Marsh Group

Bob Christian
East Carolina University
Greenville

Linda Blum
University of Virginia
Charlottesville

Lynn Leonard
University of North Carolina
Wilmington

Don Cahoon
USGS Patuxent Wildlife Center
Laurel, Maryland

Gail Chmura
McGill University
Montreal, Quebec

Rick Stumpf
NOAA Silver Spring

Dr. Courtney Hackney
UNC
Center for Marine Science

James T. Morris,
Univ. of South Carolina
Columbia

Forest

Fred Sklar
S. Florida Water Management District

Kim Williams
California State University
San Bernardino

Will Connor
Belle W. Baruch
Georgetown, South Carolina

John Rybczyk
Western Washington University
Bellingham

Tom Doyle
USGS NWRC
Layafette, Louisiana

Grace Brush
The Johns Hopkins University
Baltimore, Maryland

Courtney Hackney
UNC-Center for Marine Science
Wilmington, NC

Ben Poulter
PhD Candidate
Duke University

Habitat use

Kenneth A. Rose
Louisiana State University
Baton Rouge

Jeff Govoni
Center for Coastal Fisheries and Habitat
Research, Beaufort

Charles Peterson
UNC Institute of Marine Sciences
Morehead City
NC Science Panel on Coastal Hazards

Joanna Burger
Rutgers Nelson Biological Laboratories
Piscataway, NJ

Bruce Coull
University of South Carolina
Columbia

Lawrence Rozas
Southeast Fisheries Science Center
Lafayette, LA

Glen Guntenspergen
University of Wisconsin Sea Grant
Superior, WI

Managers

Doug Rader
Environmental Defense
Raleigh

Steve Benton
NC Division of Coastal Management

Ron Ferrell
NC Wetlands Restoration

Mike Street
NC Division of Marine Fisheries

Mike Wicker
US Fish and Wildlife Service

David Cox
NC Wildlife Resources Commission

Jimmie Overton
NC Division of Water Quality

John Dorman
NC Division of Emergency Management
jdorman@ncem.org

John Taggart
NC NEERS
Coastal Reserves Program

Bill Crowell
Dean Carpenter
Albemarle-Pamlico National Estuary
Program

Ralph.Cullom
NC Division of Forest Resources