

White Paper NOAA Workshop
North Carolina Sea Level Rise Project: Application to Management
October 2009

EXECUTIVE SUMMARY

Effective communication between scientists and managers is the key to transitioning research results into resource management activities. The North Carolina Sea Level Rise (NC SLR) Project is a cooperative network of five multi-investigative projects funded by NOAA's Center for Sponsored Coastal Ocean Research (CSCOR) through its Ecological Effects of Sea Level Rise (EESLR) Program. The NC SLR Project is the pilot study of a planned national program to improve scientific knowledge of the effects of sea level rise and storminess on coastal habitats and through this increased understanding, develop ecological models to forecast these effects. Since its beginning in 2005, the NC SLR Project has engaged NC state managers to disseminate findings and adopt their recommendations in subsequent plans. On July 16-17, 2009, CSCOR convened the North Carolina Sea Level Rise Project: Application to Management Workshop at the University of North Carolina at Chapel Hill, Institute of Marine Science, Morehead City, NC, to inform managers of the NC SLR Project's advances toward understanding the impacts of SLR on NC coastal ecosystems and toward development of maps and modeling tools to aid coastal managers and decision makers.

The North Carolina study area included the Pamlico, Back, Bogue and Core Sounds as well as the Neuse River including all coastal habitats. Five projects were funded including a storm surge inundation model and a landscape model of the entire study area as well as smaller models of the Neuse River, intertidal marshes inside Pamlico Sound and sub-tidal, SAV, inter-tidal flat, oyster, and marsh habitats of Back and Bogue Sounds. Researchers from the project met for two days with interested state and local managers and planners and provided information on the NC SLR Project's advances in understanding sea level rise and storm surge impacts on NC coastal ecosystems and the development of predictive tools to facilitate management capabilities to mitigate these impacts. Breakout groups provided valuable feedback to CSCOR and to the North Carolina Division of Coastal Management about possible management application of funded projects. The management questions potentially answered by the NC SLR Project include:

- incremental predictions of wetland stability of marshes,
- the location of migrating and non-migratory wetlands,
- vertical elevation information linking all habitats,
- effects of sea level rise on multiple parameters with feedback mechanisms to accurately predict the fate of coastal habitats under various sea level rise regimes,

- current and future information on the estuarine habitat status for estuarine dependent species managed by the NC Marine Fisheries,
- knowledge of the effects of various shoreline stabilization techniques on near shore and adjoining habitats,
- restoration guidelines to ensure restoration success with sea level rise for all estuarine habits,
- storm hazard planning and response including how habitat loss will affect flooding,
- how sea level rise will affect salinity,
- initial knowledge about the fate of the Outer Banks,
- how sea level rise will affect the inlets,
- how sea level rise and storminess will affect tidal range,
- the need for better tidal measurement within areas with small tidal signals,
- erosion rates of state estuarine shorelines,
- location of stable and unstable shorelines,
- identifying and quantifying ecosystem services at finer spatial scales, higher resolution and with geo-referencing.

In some instances, these questions can only be answered in limited sections of the study area. Spatial and temporal scales vary, depending on the model results used. The utility of the research results would be greatly improved through refinement of mapping tools and training to deliver the results to end users. The maps and tools provided by the NCSLR project are in the final stages of development and will be displayed on the planned NOAA Climate Portal.

The Workshop results demonstrate the enormous benefit of providing opportunities for management and researcher interaction during the planning and execution of a research project. The findings and tools developed in the NC SLR project have improved managers' understanding of SLR dynamics and ecosystem impacts along the NC coast. Efforts are ongoing to further transition NC SLR management tools (forecast models, visualizations, geospatial tools, mapping representations) to application.

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Purpose of the Workshop

The North Carolina Sea Level Rise (NC SLR) Project is a cooperative network of five multi-investigative projects funded by NOAA's Center for Sponsored Coastal Ocean Research (CSCOR) through its Ecological Effects of Sea Level Rise (EESLR) Program. EESLR in North Carolina is a Pilot Project for a national program with goals of a) improving scientific knowledge of the effects of long term effects of sea level rise (SLR) and storminess on coastal habitats and b) developing ecological models to forecast these effects. Since its beginning in 2005, the NC SLR Project has engaged NC state managers to disseminate findings and adopt their recommendations in subsequent plans. On July 16-17, 2009, CSCOR convened the North Carolina Sea Level Rise Project: Application to Management Workshop at the University of North Carolina at Chapel Hill, Institute of Marine Science, Morehead City, NC, to inform managers of the NC SLR Project's advances toward understanding the impacts of SLR on NC coastal ecosystems and toward development of predictive tools to facilitate management capabilities to mitigate these impacts. This White Paper summarizes the Workshop's progress in meeting the following objectives:

1. summarize results from the 5 subprojects – objectives met, knowledge gained, and tools developed;
2. identify management problems potentially solved through NC SLR Project tools;
3. determine the types of information, data products, and data presentation format that will best inform NC management of SLR effects;
4. determine the research and resource requirements for further development of NC SLR Project mapping and modeling tools to best meet NC managers' needs, including transition to sustained operation;

Applying best science for environmental management decision-making

Integrating scientific data, information and knowledge into resource management and decision-making is a challenge. Recent advancements in technology have dramatically increased the number of environmental observations and increased our understanding of the complex interactions of environmental systems. However, advanced technology has not always led to improvements in ecosystem health. How can we distill these data and environmental knowledge into better decision-making? Adding to problems in coastal management is the specter of climate change and the expectation of increasing rates of sea level rise and storminess.

Dennison (2007) recommends several steps for improving the connection between environmental research and management including focusing on environmental problem

solving by combining management, research and monitoring into integrated programs, and developing better integration and application tools to aid in the transfer of data into information and knowledge to be applied in environmental problem solving.

The Coastal States Organization (CSO) Science to Management Initiative (2005) notes that because environmental problems commonly have multiple causes, perfect knowledge is an unrealistic expectation and resource managers must have tools for managing this uncertainty. The CSO also finds that scientists and managers need opportunities for frequent exchanges for the purpose of sharing research findings and needs.

The Research to Applications Task Force of the Ocean Research and Resources Advisory Panel (2007) listed several techniques for improving the effectiveness of the research to applications transition including: prioritizing user involvement throughout the research to applications process; an environmental agency culture that places high value on transitioning by creating incentives and accountability that stimulate program managers to integrate application into their research programs; expansion of opportunities and incentives that motivate researchers to work with users toward applications; and allocation of the time, personnel, and funding necessary to support research and development through application. A unifying principle among these themes is collaboration between knowledge producers and the community of knowledge users. CSCOR's sponsorship of the North Carolina Sea Level Rise Project: Application to Management Workshop is in the spirit of better researcher to management collaboration.

The Ecological Effects of Sea Level Rise (EESLR) Research Program in North Carolina

Rising sea level will have severe impacts in low-lying coastal communities. Besides inundation, higher seas increase the risk of severe storm surges and dangerous flooding. Prudent coastal management demands preparations. North Carolina was chosen as our Pilot because high resolution LIDAR was available for the entire coastline. With guidance from the North Carolina scientific and management communities, CSCOR convened the *Ecological Effects of Sea Level Rise Workshop: Research and Management Needs* at the NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) in Beaufort, NC on February 4-5, 2004. The workshop objective was o developing a research strategy to provide coastal managers the information and tools needed to mitigate the ecosystem impacts of sea level rise. Using these recommendations (see White Paper at http://www.cop.noaa.gov/products/multimedia/presentations/mt-2004-beau-cc/sea_level_rise_wp.pdf), CSCOR's EESLR Program established the NC SLR Project in fall 2005, targeting a study area chosen by the North Carolina Department of the Environment and Natural Resources (DENR) that included the Neuse River, and the Southern Pamlico, Back, Core, and Bogue Sounds. The NC SLR Project includes NOAA, university, and state investigators collaborating on the following subprojects:

1. Advanced Circulation Hydrodynamic Model (ADCIRC) populated with bathy/topo relative to a single datum (NAV88) and a Digital Elevation Model (DEM)- Coast Survey Development Lab; Jesse Feyen Lead PI
2. Ecological Effects of Sea level Rise on North Carolina Marshes (U of South Carolina, Vanderbilt, East Carolina University)- James Morris lead PI
3. Modeling Estuarine Habitat Response to Rising Water Levels (University of North Carolina, Institute of Marine Science) Charles Peterson lead PI
4. Shore Zone Modification in Response to Rising Sea Level in North Carolina Marshes (East Carolina University) Reide Corbett lead PI
5. Neuse Landscape Model Enrique Reyes lead PI

Because resource management and land use decisions are made by state and local officials, CSCOR has from the outset, engaged with resource managers to ascertain needs. On January 31, 2007 -February 1, 2007 at the North Carolina Aquarium at Pine Knoll Shores, NC, CSCOR sponsored a manager's workshop, *Planning for the Impacts of Sea Level Rise and Climate Change*, to solicit guidance from the coastal management community for designing scientifically informed modeling and mapping tools that would assist governing agencies and businesses located in North Carolina's coastal zone (see North Carolina Managers Meeting Fact Sheet at http://www.cop.noaa.gov/stressors/climatechange/features/SLR_manager_handout.pdf).

Summary of Research

1) Advanced Circulation Hydrodynamic Model (ADCIRC) populated with bathy/topo relative to a single datum (NAV88) and a Digital Elevation Model (DEM)

J. Feyen and K. Hess Coast Survey Development Lab

Focus of Research

A model to study the impacts of long term sea level rise (SLR) on coastal circulation has been implemented in the coastal North Carolina sound system. This area is particularly vulnerable to SLR, as a fragile system of barrier islands protects the extensive but sensitive estuarine system. The leading impact of SLR is on the hydrodynamic response of the system: water level, circulation, and inundation patterns can all change in response to rising sea level.

Therefore this research study was commenced to examine the ability of the two-dimensional hydrodynamic model ADCIRC to simulate tides, regional synoptic wind events, and hurricane storm surge flooding before and after SLR in order to examine circulation changes. Accurate simulation of coastal circulation and inundation was accomplished via high resolution in the coastal zone, continuous bathymetric and topographic data referenced to a consistent datum, and an accurate flooding model. The model was validated against observational data before modification of initial and boundary water levels to represent eustatic SLR.

In order to manage the future effects of SLR, coastal managers need to know the local impacts of global SLR, but also future physical conditions, habitats that are at risk, and loss of ecosystem services due to changes, and must understand the degree of confidence in predictions of these changes. It is challenging to predict environmental conditions decades in the future as there are a wide range of variables (e.g.,

isostasy, erosion, storm variability, anthropogenic effects), where SLR is just one of a number of significant processes. Therefore, limited confidence can be drawn from the skill of these models to accurately predict a future snapshot of the coast. However, further understanding of the processes involved and the types of risks that exist because of SLR can be examined with study outcomes.

Results Obtained

The ADCIRC model computed different scenarios of SLR to examine changes in tidal shorelines, tidal conditions, and coastal inundation. The use of a dynamical model was advantageous because this model has a demonstrated history of accurate water level simulation, nonlinear interactions of multiple phenomena can be captured via the governing equations, and it is a prognostic tool that can guide “what if” scenarios when multiple changes affect the hydrodynamics (e.g. SLR and storm surge, SLR and barrier island loss).

First, changes in tidal conditions were calculated combined with the effects of SLR. Updated tidal datums were calculated under SLR scenarios of 0.25, 0.5, and 1.0 m. These results demonstrate changes in sea level, high tide, low tide, and tide range that can be studied. For instance, by simply raising sea level, North Carolina’s tidal inlets are effectively enlarged, increasing the tidal range with the sounds. Furthermore, NOAA’s charted shoreline is determined by the Mean High Water datum. Model-based datum fields for the SLR scenarios were intersected with topography to illustrate the change SLR alone would have on shoreline. While this is not a future prediction of shoreline position because it lacks many other processes (e.g. geomorphologic, biologic, anthropogenic), it does illustrate areas of vulnerability.

One significant concern in North Carolina is potential loss of a part of (or even most of) the Outer Banks to storms, sea level rise, or a combination thereof. Tidal simulations of the sound system were performed to demonstrate the change in conditions within the sound system if such a situation were to occur. Results point to a transition of the Pamlico and related systems from subtidal to tidal as barrier island losses increase.

Third, the model was utilized to study hurricane storm surge flooding of the NC system and the significance of changes in flooding with SLR. Hurricane Isabel from 2003 was used as a test case to examine the changes in inundation that would occur with 0.5 or 1.0 m of SLR. With a validated model using conditions observed during the original storm, it was possible to show the significance of flooding that could occur if sea level was at a higher point.

Management Application

Even though they may be hard to specifically predict, we can expect that coastal changes will occur with SLR. Physical impacts could include shoreline retreat, loss of habitat, alteration of hydrodynamic conditions, and increased flooding. While present modeling techniques are limited in their ability to parameterize all of the environmental changes that will occur over the next 50 to 100 years, these results do indicate that a threat exists. The results can be used to identify vulnerable areas where coastal habitats are threatened, and management action can be taken to protect against loss.

With the output from this modeling study it is possible to envision how the shoreline might change due to SLR, or how tidal conditions within the sounds might change with barrier island loss, or how SLR will exacerbate inundation during storm surge events. Coastal resource managers can determine which areas are most vulnerable to these impacts. Land use planning can consider loss of coastal land and increased coastal flooding levels. Protections against land use change could be examined more critically by considering future potential shoreline and the associated habitat loss, accounting for the natural need of habitats to migrate inland in respond to SLR. The bottom line is that this study enables generalized global

predictions that can be visualized as impacts in North Carolina on a local scale. While the modeling did not account for all factors that will play a role in defining environmental change, it does enable action to be taken to insure coastal ecosystems against the risk of climate change.

Finally, this research can be used to illustrate SLR impacts to the public. This model output may be considered more illustrative than predictive, but enables intuitive graphical display of changes in shoreline and inundation that could help illustrate the importance of considering these risks in planning and protecting the environment.

2) Ecological Effects of Sea-Level Rise on Coastal North Carolina Marshes

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Cahoon, US Geological Survey R.R.Christian, East Carolina University

Focus of Research

This project was conceived to forecast effects of rising sea level on the condition of intertidal marshes inside Pamlico Sound, NC. One important goal of the research was to determine through combined modeling and field studies if present day marshes are currently keeping pace with sea level. With modeling tools that were developed, we planned to generalize our results to coastal wetlands that were not included in the field study and to forecast future trends.

Field experiments were started in March 2006 at the Cedar Island NWR site at the end of Lola Rd and at Pine Knoll Shores (PKS). At both sites measurements were made in two marsh communities, one dominated by *Juncus roemerianus* and the other by *Spartina alterniflora*. These are the plant species that dominate the marshes of Pamlico Sound. *Juncus* is more common today, but *Spartina* is likely to become more important as the salinity of Pamlico Sound increases with rising sea level. Major field experiments included measurements of the change in surface elevation within these marsh communities and bioassay experiments in which these two species were grown at different relative elevations in experimental planters, termed marsh organs. Changes in marsh surface elevation were made using sedimentation-erosion tables or SETs.

Results Obtained

Plant Growth

We monitored the growth of plants and sediment salinity as a function of elevation in the experimental planters. The standing biomass density B_s (g/m^2) of the plant community changes with a number of environmental conditions including the relative elevation of the marsh surface (Figure 1). Provided that the marsh platform (marsh surface) elevation is supraoptimal for growth, positive changes in sea level or mean high water (MHW) will raise primary production (Figure 1). For any intertidal species, there must be upper and lower limits of relative elevation

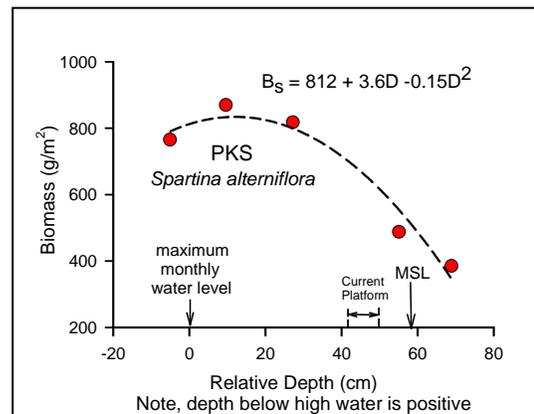


Figure 1 Biomass density of *Spartina alterniflora* grown at different relative elevations within the intertidal zone. Elevation is shown as depth below the mean maximum monthly water level at the site.

determined by hypoxia at one extreme and osmotic stress at the other. The biomass density distribution can be approximated by a parabola with an optimum depth (depth below MHW) that is bounded by upper and lower limits (Figure 1): $B_s = aD + bD^2 + c$. This curve can be viewed as dimensions of a species' fundamental (in the absence of competitors) or realized (in the presence of competitors) niche, *sensu* Hutchinson (1957).

Shown in *Figure 1* is the annual growth of *Spartina* as a function of its elevation within the intertidal zone. Also shown is the current elevation of the marsh platform at the PKS study site and maximum monthly water level (defined as zero depth). This is an important experimental result, because it demonstrates that the current depth of the marsh below maximum high water is greater than the optimum depth. Consequently, plant growth will decline when sea level rises. As plant growth declines, sedimentation rates will decline and the relative elevation of the marsh will fall further behind sea level. This is an unstable condition. It suggests that our study sites have passed a tipping point.

Marsh Elevations

Table 1. Accretion rates (change in marsh surface elevation) in field sites by site, experimental treatment, and dominant plant community.				
		Replicate	Species	Accretion Rate (cm/yr)
Lola Rd.	Control	1	<i>Juncus</i>	0.26
		2	<i>Spartina</i>	-0.14
	Fertilized	1	<i>Juncus</i>	0.22
		2	<i>Spartina</i>	0.12
Pine Knoll Shores	Control	1	<i>Juncus</i>	0.36
		2	<i>Spartina</i>	0.06
		3		-0.42
	Fertilized	1	<i>Juncus</i>	0.19
		2	<i>Spartina</i>	0.56

In general, we found that in field sites that were not fertilized, or control sites, the rate of change of elevation over the 3-yr study was not great enough to keep up with the current rate of sea-level rise (Table 1). Two sites dominated by *Spartina* actually lost elevation. We were able to increase the rate of accretion at all sites dominated by *Spartina* by fertilizing the marsh with a commercial fertilizer. Fertilizing sites dominated by *Juncus* either had no effect or may have decreased the rate of accretion.

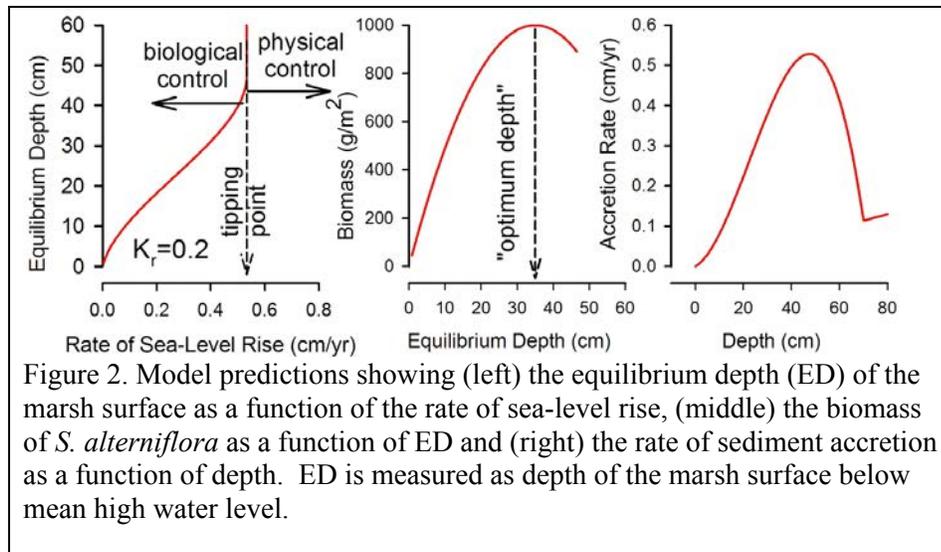


Figure 2. Model predictions showing (left) the equilibrium depth (ED) of the marsh surface as a function of the rate of sea-level rise, (middle) the biomass of *S. alterniflora* as a function of ED and (right) the rate of sediment accretion as a function of depth. ED is measured as depth of the marsh surface below mean high water level.

Modeling

We made progress on the development of a theoretical model that generalizes about the behavior of coastal wetlands and that can use empirical results like those presented above to make specific predictions. The derivation of the model is omitted here for brevity, but it can be simply described

as a 0-D model that computes the equilibrium depth of a marsh surface as a function of biomass production, the concentration of suspended solids in the water column (C), tide range (T) and sediment bulk density. With it, the rate of change of elevation of the marsh surface, dZ/dt , can be expressed as a function of a single variable, depth D :

$$dZ/dt = [D(c+aD+ bD^2)k_sC + DCq+(c+aD + bD^2) k_rT]^2/[T(DCq\alpha+(c+aD+bD^2) (Dk_sC\alpha + k_rT(\alpha-\beta)))]$$

This model equation makes a number of insightful predictions that lead to a much greater understanding of the dynamics of coastal wetlands and their interactions with the sea (Figure 2). For instance, salt marsh biomass density and sediment accretion rates are functions of the depth of the marsh surface below MHW and, hence, functions of the rate of RSL (SLR). There is a tipping point. When the rate of RSL rise exceeds a critical level, yet to be determined for Pamlico Sound but about 5 mm/yr in a marsh with much higher suspended sediment concentrations, the equilibrium depth of the marsh surface eventually drops below the range of the vegetation. In other words, the vegetated marsh is stable only when the rate of RSL rise is less than about 5 mm/yr (at North Inlet), which is only a little greater than the current long-term rate of 0.35 cm/yr measured at NOAA's Charleston Harbor gage. The rate of global averaged sea level rise is accelerating (IPCC 4AR), suggesting that there may be massive losses of salt marsh habitat in the next few decades. We think that the loss of marsh elevation we see at our field sites (PKS and Lola Rd) is consistent with these model predictions.

Management Application

We have a theoretically sound method for assessing the current condition of coastal wetlands by measuring their relative elevation. With knowledge of the growth response of the marsh vegetation to relative elevation, and knowledge of the relative elevation of the marsh surface it is possible to determine if marsh elevation is superoptimal, and stable, or suboptimal and unstable. It should be possible to utilize LIDAR for this purpose. The result would be a map showing the distribution of marshes that respond positively to sea level rise, and marshes that respond negatively. This would inform managers about the changes in the distributions of marshes that

are likely to occur in the future. This information could be used to determine set back requirements for development in the estuary. Marshes will not disappear from Pamlico Sound, but they will migrate inland (transgress), provided that bulkheads or other obstructions allow.

3) Modeling estuarine habitat response to rising water level

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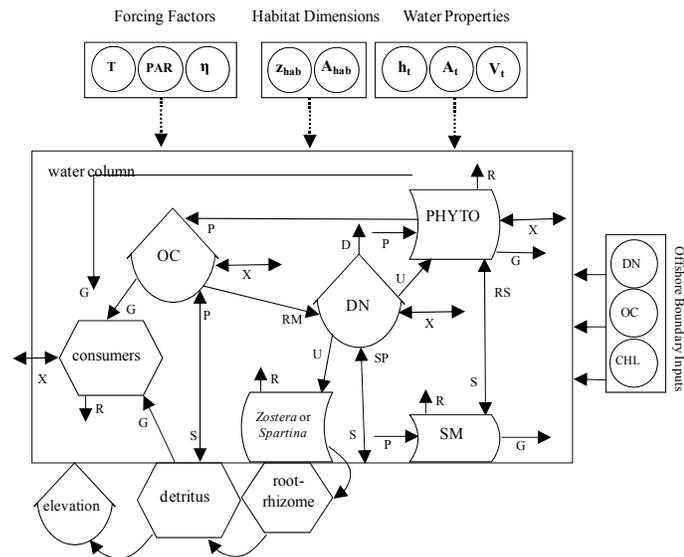
Focus of Research

We developed a habitat simulation model and used it to forecast the effects of increased sea level and shoreline hardening on the productivity of habitats representative of much of the US Atlantic coast. Because human responses to rising water levels are a significant driver of delivery of coastal ecosystems services, we considered the impacts of shoreline hardening in our study. We conducted field research to test hypotheses about ecological impacts of changing sea level and shoreline hardening to provide data for model development and calibration.

Results Obtained and Applications to Management

Habitat simulation models

Mathematical models were developed to simulate the effects of relative sea level rise on estuarine habitats. A geographic information system provided estimates of habitat elevation, patch size, and distribution. Forcing functions included changes in water level, depth, wetted area, volume, light, and temperature every 45 min over the 40 y simulations. Annual habitat carbon budgets were a primary response variable. This spatial-mathematical modeling approach will provide important information about the function of estuarine systems for decision makers.



Estuarine productivity matrix

Estuarine primary, secondary and tertiary productivity data from the eastern U.S. were synthesized. This matrix revealed surprising patterns and provides a template for restoring and preserving estuarine ecosystem function. Estuarine habitat management demands a more holistic approach to sustain food web services. Information like this will facilitate sound decision making and consideration of values beyond the most apparent (i.e. primary production).

Trophic level	Habitat				
	<u><i>Spartina</i> marsh</u>	<u>Intertidal flat</u>	<u>Subtidal flat</u>	<u>Seagrass bed¹</u>	<u>Oyster reef</u>
Primary - 1 ⁰	688	222	135	960 1431	330
Secondary - 2 ⁰	66(±6)	75(±18)	73(±17)	79(±26) 89(±14)	1635(±360)
Tertiary - 3 ⁰	24(±6)	22(±12)	23(±8)	15(±4) 6(±2)	47(±5)
Ratio of 1 ⁰ :2 ⁰ :3 ⁰	100 : 9.6 : 3.5	100 : 34 : 10	100 : 54 : 17	100 : 7 : 0.9	100 : 505 : 14
Weighted sum by Lindemann 10% efficiency	3,748	3,172	3,165	3,250 2,921	21,380
Weighted sum by inferred efficiencies of 26 and 27%	1,284	824	743	1,483 1,859	7,288

Table 2. Average (±1 SE) productivity (g AFDM m⁻²y⁻¹) at the three lowest trophic levels in each of five estuarine shoreline habitats and within habitat ratios of 1⁰:2⁰:3⁰ production, derived from synthesis of available data from Texas to Massachusetts, USA. Primary productivity was adjusted to account for necessary microbial transformation of vascular plant detritus to produce suitable foods for detritivores. Weighted sums across the three trophic levels are computed in units of primary production required to produce observed average productions, assuming first Lindemann 10% ecological efficiencies at each conversion to the next highest trophic level and second empirical efficiencies derived from averaging within-habitat productivities across all habitats except oyster reefs. No SE is provided for primary production because the value combines empirical data and modeled estimates.

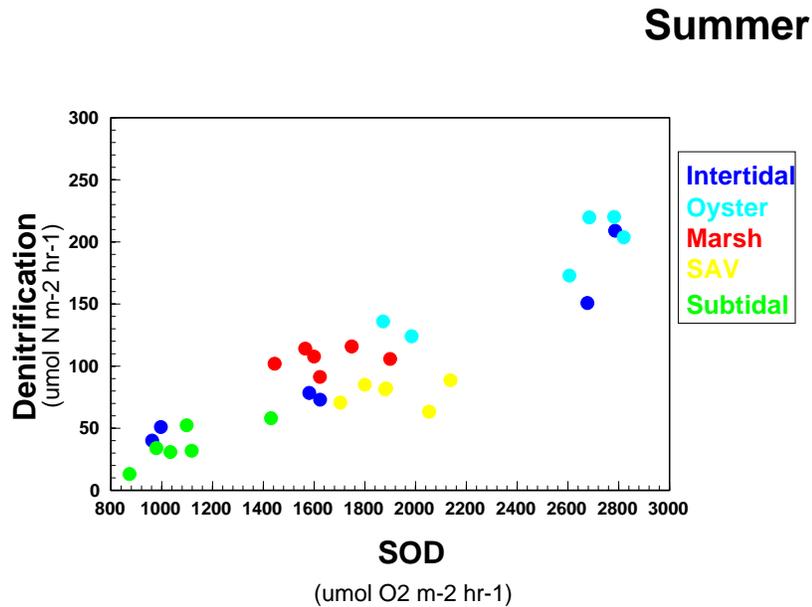
Marsh assessment metrics

Under US law, federal and state governments have joint responsibility for facilitating restoration to compensate quantitatively for ecosystem services lost because of oil spills and other contaminant releases on tidal marshes. This responsibility is now met by choosing and employing metrics to quantify injury and scale restoration accordingly. Here, we reviewed potential metrics that might refine or replace present metrics for marsh injury assessment. This guidance is currently being used by NOAA to inform their role as trustee of US marine resources.

Habitat- specific Denitrification

Using data gathered in this project we constructed a spatially and temporally explicit model of shallow water estuarine denitrification. Measured data are shown in this figure, demonstrating the strong correlation between sediment oxygen demand (SOD) and denitrification across habitats. This model has been used in management decisions regarding conservation and restoration of estuarine habitats.

Additionally, monetary values of the habitat-specific denitrification rates were determined, increasing both utility and applicability.



4) Quantifying and Evaluating the Effects of Rising Sea Level in NC

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Focus of Research

Coastlines are constantly changing due to both natural and anthropogenic forces. Climate change and associated sea level rise will undoubtedly reshape our coasts. No longer are ocean fronts the only concern of short-term shoreline change. Shoreline dynamics along more sheltered estuaries have gained attention and are needed to better understand and protect coastal resources. Recognizing and understanding the complex causes and dynamic processes involved in shoreline erosion and shorezone alteration, including the ensuing ecological change in state and function is necessary to minimize the erosion impacts and managing our shoreline resources and economic investments. This study, conducted in the Neuse River Estuary, evaluated the rate of sea-level rise over the last several centuries and the ensuing shoreline and shorezone change over a recent 4-decade period (1958-1998) to further our understanding of what changes may occur in the near future. In addition, we measured the rate of shoreline change and the ecological effects of sea-level rise on the shorezone, defined here as the area of wetland that extends from an estuarine shoreline landward to where the hydrologic influence of sea-level diminishes and terrestrial hydrology dominates. Analysis of estuarine shoreline change and the influencing parameters in these complex systems offers insight on future changes and information useful for management practices.

Results Obtained

Records of relative sea level from two salt marshes since AD 1500 were used to complement existing tide gauge records and to determine when recent rates of rapid sea-level rise commenced. Reconstructions were developed using foraminifera-based transfer functions and composite chronologies that were validated against regional 20th century tide-gauge records. The absolute rate of relative sea-level rise in North Carolina during the 20th century was 3.0 to 3.3 mm/yr, which began at the end of the 19th century and is broadly synchronous with other studies from the Atlantic coast.

Throughout the recent decades various methods have been developed to calculate shoreline change and multiple parameters have been correlated with estuarine erosion, including fetch, wave energy, elevation, and vegetation. This study analyzed parameters associated with estuarine erosion at two contrasting scales, global (whole estuary) and local (estuary partitioned into 8 sections, based on orientation and exposure). With a mean shoreline-change rate of -0.58 m yr^{-1} , the majority (93%) of the Neuse River Estuary study area is eroding. Although linear regression analysis at the global scale did not find significant correlations between shoreline change and the parameters analyzed, general trends were determined at the Local Scale. Local Scale analysis determined higher erosion rates, higher elevation, and lower exposure and fetch up-estuary. The mean shoreline-change rates of Wetland shorelines displayed the lowest correlation ($R^2=0.25$, $p=0.208$), suggesting Wetland shoreline change response is independent of fetch. The general trends found at the Local Scale highlight the importance of the spatial distribution on shoreline-change rates and parameters analyzed within a complex estuarine system, like the Neuse River Estuary.

Finally, we investigated the geomorphology, hypsography, wetland types, and average landscape slope of successive interstream divide units within the Neuse River Estuary that are submerging relative to rising sea-level. A geographic information system (GIS) was used to identify differences between units and translate them into a space-for-time framework consisting of four temporal stages of shorezone transgression: early – upstream migration, intermediate – non-migration, late – over-flat migration, and terminal – non-migration. The framework is intended to provide a better understanding of processes that have led to the current position of shorezones and to anticipate where effects of rising sea-level will be the greatest.

Management Application

Predicting geomorphic change in the coastal system as a result of sea-level rise is a complex challenge. Issues to be considered in modeling geomorphic response include the multiple complex interrelationships (both positive and negative feedbacks) between coastal hydrodynamics, the geological framework, geomorphology, sediment erosion, transport and deposition, and structural biological habitats. This research provides the foundation for predicting coastal change in North Carolina and beyond. The recent rate of sea-level rise evaluated during this study can be used as the base for forecasting geomorphic responses in the near future. Maps of shoreline change rates for the Neuse River Estuary have been made available to local and state agencies. Maps and other GIS-based decision-support tools

associated with the change in shoreline and shorezone could be developed based on this research effort.

5) Neuse Landscape Model

Enrique Reyes lead PI

Focus of Research

The best management approaches to complex natural systems such as coastal marsh ecosystems are rational, holistic, and able to combine information from several disciplines. Simulation models use such an approach. The ability of models to project cumulative impacts at the different temporal and spatial scales makes them extremely useful for the management of complex systems. The inherent predictive nature of simulation models allows the ecosystem manager to evaluate diverse scenarios and their consequences. Particularly, the need for a regional coastal model is based on the simple fact that the habitat changes and wetland flooding due to increased sea level rise into the coastal zone are driven by long-term and complex physical and biological processes. As sea level rise continues to accelerate, substantial hydrological modifications will occur across diverse scales. To predict the sequences of increased hydrological changes and, consequently, fluxes of salinity, sediments and inorganic materials on coastal waters, a synthesis of available information must be done at different scales. For the coastal zone this requires that oceanographic and landscape models must be coupled. The goal of the present project is to *produce an integrated forecast* of environmental consequences of long-term effects of sea level rise and climate change on North Carolina's coastal habitats aimed to aid natural resource managers.

Results Obtained

The long-term watershed scale model was designed to simulate processes occurring over decades. Most previous similar studies are based on a modeling technique in which the landscape is divided into a grid and each resulting cell is modeled individually with exchanges of water and materials among its neighbors. Model forcing includes subsidence, sea level rise, changes in river discharge and tidal regime, and climate variability. The Neuse Landscape Model (NLM) was designed to predict landscape succession and evolution and to estimate the usefulness of management approaches such as wetland and hydrologic restoration for the coastal habitats.

As proof that a model is capable of predicting long-term changes, a calibration experiment is required. The regional model simulated processes over a 10-year time scale and where spatial calibration was performed in three steps. First, the model was run repeatedly until the land/water ratio matched the initial habitat map, then the habitat type proportions were calibrated, and finally the habitat distribution was determined. For land/water ratios, the NLM was run using the 1988 forcing functions exclusively until stable conditions were reached and all modules were running concurrently. Spatial calibration was done by comparing the simulated 1997 model and USFWS habitat classified map using a goodness-of-fit statistic between them. The calibration experiment yielded a fit of 92.4 for the NLM.

After the calibration experiment proved satisfactory, two future scenarios were developed to investigate potential consequences of sea level rise. The first scenario was implemented using the present North Carolina sea level rise rate (3.8 mm/yr). The simulation run was initiated in 1991 and ran for 50 years. The resulting image at time 2001 and the final image at time 2041 can be compared using our fit statistic against the 2001 habitat classified image. These results indicated that under the present sea level rise rate, swamps and open water habitat are being replaced by brackish marsh as a result of increased and permanent flooding and quiescence waters. This change occurs generally along river edges (and especially on the river basins in which stream data were missing). It is also notable that the forested habitat and swamps do change to other type of habitats.

The second simulation scenario implemented represented the response to a catastrophic change in global weather (unlikely, but possible). A sea level rise rate of 50 mm/yr was used to explore the changes expected under significant increased flooding. Under this scenario barrier islands become wider due to over wash, resulting in a larger protective barrier to interior marshes. Brackish marshes continue to expand along with salt marsh as these two habitat types replace swamps, forest and open waters.

Management Application

Faced with potential land loss, as a result of increased sea-level rise and subsidence, the State of North Carolina requires tools to analyze coastal ecosystem response. The NLM aims to integrate and develop a landscape model to assess the quality and quantity of spatial and temporal habitat change for the eastern North Carolina coast under diverse sea level rise scenarios. The NLM considers large-scale effects of non-point and punctual impacts, providing a regional view and evaluation, and allowing the exploration of future trends of ecosystem response to climate change in general and sea level rise in particular.

The information products and decision-support tools that might be developed based on this modeling effort include prioritization maps and geo-databases, including sensitivity analyses and using GIS. Another product could be a library of scenarios where the user can run the NML with existing data or have to find required data. NLM results could be related to CHPPs (Coastal Habitat Protection Plans) habitats to ensure model interfaces with CHPP classifications. There may be model accuracy issues related to marsh migration, because fill (and other erosion control structures) prevents marsh from migrating inland and therefore the habitats may not respond as predicted. The NLM needs to incorporate real time land conversions, i.e. development, clear cutting, in order to stay as current as possible.

Outreach and public education through easy to use maps and tools will help inform the public on what future habitat landscapes will look like under various sea level rise and storm surge scenarios. The public can then push for better land use planning and influence commission decisions. Locally, counties can look to other areas, such as Wilmington, for illustration of land use planning as well as hazard mitigation.

Manager Presentations at the Workshop

1) Geovisualization for Sea Level Rise

T. Allen, East Carolina University

Visualization, geospatial tools and mapping representation of sea-level rise are needed to communicate the most up to date scientific knowledge to decision makers and the public. Geovisualization can integrate geographic information and spatial analysis and raise awareness through depiction of current conditions and future possibilities. Geographic information systems (GIS) and remote sensing technology represent the state of the art techniques for communicating how the coast is changing due to sea level rise and erosion. However, when these powerful technologies are used to communicate coarse resolution topographic information using “bath tub” models, decision makers get poor information that over-generalizes ecosystem responses.

State and local governments may be making the most important decisions regarding the eventual impact of rising sea level on the United States. State and local governments create the land use plans and issue permits that determine whether the areas at risk will be developed. What kind of shore protection will be required to protect both infrastructure and near-shore habitats as the sea rises. Will land be required to remain vacant enough for wetlands to migrate inland? These are local decisions that geospatial tools can help answer.

By using visualization, geospatial tools and mapping representation to highlight and communicate the research results of the NOAA NC Sea Level Rise Project, science can better inform decision making. Our various models use up to date hydrodynamics and wetland modeling techniques to accurately represent the interactions between geomorphology, ecology and sediments dynamics. Through the developing of geospatial tools to accurately represent our modeling results, the best science can be delivered in a format that is easy to understand. However, proper tool development benefits from user input!! By asking potential users what questions they need to answer through these tools, utility will improve.

Thus, the integration of managers and stakeholders input into the design of GIS products is the goal of NOAA management. Only through management input can we properly synthesize and communicate our funded scientific results in a useful way.

2) Future Decisions on Sea Level Rise Policy and Design Criteria

T. Devens, PE, MCE North Carolina Department of Transportation

The presentation focused on the application of Sea Level Rise research; specifically decisions to be made in response to scientists’ findings. There are various classifications of decision makers as well as the types of decisions that will be made – on federal, state and local levels. There are general land use and infrastructure challenges arising from SLR, focusing on impacts to transportation and municipal infrastructure. When planning for sea level rise, there is a need to modify appropriate engineering design criteria and consider risk-based decision making models. Often current environmental laws assume static sea level, such as management and preservation of wetlands and endangered species habitat. Land use planning is an important (and perhaps controversial) aspect of future preparation for SLR. Great Britain’s adoption of Prescriptive Architectural Guidance is an example of proactive planning/regulatory measures – incorporating

SLR planning restrictions such as minimum elevations, bathymetric approach, increased design rainfall and wind loads, etc., when considering future infrastructure plans. If decision-makers are faced with a multiplicity of research results, then central planning factors such as sea level may be determined using non-scientific methods. “Scientific consensus” from researchers for planning purposes carry more influence on policy and design criteria development than is achieved by independent results that dramatically differ. Independent research is important and must maintain integrity; however NOAA, Sea Grant, and other research sponsors might consider a final phase whereby independent researchers have an opportunity to compare their independent research and arrive at central consensus figures and supporting “windows of behavior” that better aid decision-makers to develop (and defend) appropriate policy and design criteria. This approach might best result in “Good Decisions based on Good Science.”

Transportation managers decision makers need f specific products such as: projected sea level elevations in 25-year increments (with a central “consensus” and high & low boundary), GIS-based 25-year projections of shoreline, wetland, and habitat boundaries, and further study of storm intensities in recent years – to determine if rainfall intensities for design storms are still appropriate.

3) Planning for Sea Level Rise: Managing the Coastal Mosaic

D. J. Marcucci, PhD, MLA, AICP East Carolina University

Climate change and the associated sea-level rise are phenomena that challenge not only scientific investigation but also coastal planning and management decisions. We have enough science to understand the essential logic: global climate change will occur over the next century causing a measurable increase in sea level, which will be associated with coastal storms disturbing both landscapes and estuaries to a greater extent. This sequence is likely to alter a variety of phenomena: estuarine ecology, bathymetry, periodic inundation, permanent inundation, shoreline erosion, ecosystem changes, landscape ecology, and coastal hazards. What we do not have are the planning structures to develop scenarios and make adaptation decisions. Furthermore, we will especially need to analyze and plan at landscape and regional scales.

Local planning focuses on relatively short-term scenarios (twenty years) that are dependent on reasonably foreseeable trends. The longer the timeframe extends the greater uncertainty exists in the forecasts. Decisions potentially impacting current lifestyles and economics have traditionally been based on forecasts with a high level of certainty. Nonetheless planning researchers consider sea-level rise to be a “slow disaster,” which demands attention. Therefore planning for sea-level rise becomes an issue of managing for the most likely scenario while protecting against unacceptable events that might lie at the extremes of the forecasts.

It is not enough merely to say that sea-level rise mandates retreat, and leave it at that. Individuals will desire to experience and develop coastlines while they can, possibly even in the face of increased risk. Any plan for sea-level rise will create winners and losers. Planning for sea-level rise will require a collaborative process with equitably identified stakeholders who can envision the broad scope of 50, 100, or 500 years.

A discussion of planning for sea level rise must begin with the questions of what processes create the coastal mosaic, and who controls the coastal mosaic. Of all landscape mosaics, the coastal mosaic is perhaps the most precarious. Because of the inherent stability, specialization, and richness of ecosystems in the coastal zone, planning and management decisions must fundamentally be seen as environmental decisions. But this is in the face of increasing intensification of coastal land uses.

The coastal mosaic is controlled at numerous levels. First and foremost are the actions of property owners to use and develop the land as they see fit. The ability to do this, however, is enabled or not at all levels of government. Through jurisdictional responsibilities, the federal, state, and local governments have an important role to play in shaping the coastal mosaic. A myriad of government actions influence coastal management including: flood insurance, storm surge mapping, Coastal Barrier Resources Act, infrastructure development, conservation planning, Coastal Area Management Act (North Carolina), zoning, and permitting.

We are certain of the direction of sea-level rise: the prime uncertainty lies in the magnitude. Nonetheless, how the coast is used yields clues to adapting to sea-level rise. The following types of coasts exist and will have to adapt to sea-level rise in the long term.

- Working (rural) coasts
- Resort recreational coasts
- Urban coasts
- Conservation (ecological) coasts
- Historic coasts
- Extractive coasts

Planning for climate change adaptation in general and sea-level rise in particular exposes gaps in practice. These gaps will occur at the spatial and temporal scales. As critical as a public planning process will be to lead to effective management decisions, the gaps in current practice will have to be addressed. Infrastructure and other built forms will have to be scrutinized not only for their ability to survive more extreme weather and inundation but also for their projected useable life. The resilience of communities and landscapes will be an important question for planning for sea-level rise. The effectiveness of a town that is entirely on a barrier island to plan for sea-level rise is limited. With respect to the scoping of issues, several adjustments will have to be made to current comprehensive planning practice. Changes in bioregions and migration of ecosystems will become an increasingly important issue. The emerging concept of green infrastructure will become a valuable tool. Landscape and regional scale planning will be critical in addressing sea-level rise adaptations.

4) Strategic Habitat Area (SHAs) Planning and Sea Level Rise

S. Chappell NCDENR

The first of four Strategic Habitat Area (SHA) assessments occurred in the Albemarle Sound and the northeast coastal ocean. The location and designation of SHAs is required by the Coastal Habitat Protection Plan (CHPP); a state-mandated guidance document for protected coastal fish habitat in North Carolina. The assessments identify and designate Strategic Habitat Areas using

ecologically based criteria relating habitat, alteration factors, and fish abundance data. Assessment regions cover the coastal plain portion of coastal draining river basins downstream through their connection with coastal ocean water out to the limit of state jurisdictional waters. Strategic Habitat Areas are defined in the 2005 CHPP as “Specific locations of individual fish habitats or systems of fish habitats that have been identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity.” From a management standpoint, SHAs represent priority areas for protection and restoration.

What is selected?

- An adequate representation of each **unique habitat type** so that biodiversity and critical **fish functions** found within an ecosystem are sustained (Noss 1987; Hunter et al. 1988; Ward et al. 1999; Airame et al. 2003).

How much is selected?

- A subset determined by **target representation levels** (cannot protect and/or restore the entire area due to alternative and incompatible socioeconomic uses).
- Levels based on relative magnitude of historic losses, rarity and importance of habitat to fish, and sensitivity to alteration
- The 42 unique habitat types or natural resource targets fall under 6 basic habitat types described in the 2005 CHPP.
- We also used 10 habitat subtypes to apply alteration factor rating.

The subtypes are streams, shell bottom, hard bottom, riparian wetlands, interior wetlands, shallow flats, deep waters, creeks/streams, riparian uplands, and submerged aquatic vegetation. There were 3 types of stream based on elevation, several types of wetland based on combination of estuarine/riverine, forested/emergent, and water regime (wet, mostly wet, and mostly dry), 4 types of shell bottom (intertidal/subtidal, low density/high density), 2 types of SAV (low salinity, high salinity), and several types of soft bottom based on combinations of estuarine/riverine/marine and depth category (0-3', 3-6', and >6'). Representation levels for resilient and/or widespread habitats such as deep soft bottom were set very low. Relative rare and structured habitats such as SAV and shell bottom were set at the highest representation levels. Representative areas were selected based on function and alteration level. Function level was based on co-occurrence of habitat types and presence of corroborating fish data and/or ecological designations in an area.

There are three basic categories of alteration: hydrology, water quality, and physical habitat; and 18 alteration factors. Using these categories we calculate a total alteration score for each habitat area. The scores are broken into categories for protection, enhancement, and restoration.

Oyster Sanctuary Program

S. Slade NC DENR

This program was created to provide a suitable substrate for natural oyster spat attachment for the purpose of oyster restoration in Pamlico Sound and its tributaries. These constructed sanctuaries are protected from the taking of oysters which hopefully allow these oysters to be undisturbed so that they may adapt to existing conditions. Sites are selected by biologists on the basis of salinity, bottom type, tidal flow, exposure to wave action, historical oyster data,

prevailing winds and location of other natural oyster rocks along with input from public interests. The material used to construct these oyster sanctuaries is limestone rock (Class B Rip-rap).

Due to recommendations from the 1995 Blue Ribbon Advisory Council on Oysters to rehabilitate the oyster population in North Carolina the Artificial Reef Program and the Shellfish Rehabilitation Program cooperatively constructed five Oyster Sanctuaries/Artificial Reefs between 1995-96. The Artificial Reef Program provided the funding for the materials and the Shellfish Program deployed the materials. At present a total of ten sanctuaries have been constructed using Class B Rip-rap limestone (football-basketball size rock) and are located in the following North Carolina's estuaries: Croatan Sound, Deep Bay, West Bay, Bogue Sound and Clam Shoal (AR- 296), Neuse River, Middle Bay and Pamlico Sound.

How will sea level rise affect the selection criteria of oyster sanctuaries:

- Encroachment of salinity wedge
- Hydrographic modeling
 - Hydrodynamics for larval dispersal
 - Sediment transport
 - Depth increase and/or burial of Pamlico Sound floor
 - Mapping movement of hypoxic/anoxic events

How Sea Level Rise research can aid our SHA planning

- **Include low elevation upland areas in SHA nominations?**
- **Employ habitat switching model?**
- **Consider vulnerability to SLR in expert modifications.**
- **Adjust location of habitat creation, restoration, and enhancement efforts to account for changing salinity patterns and depth/energy**

5) NC Sea Level Rise Planning

T. Miller NC Division of Coastal Management DENR

The North Carolina Division of Coastal Management (NCDQM) has initiated a process to plan for future sea level rise. First, NCDQM is gathering public perception of the problem through a public stakeholder survey. Survey results will be available in January 2010. The survey will identify perceptions of risk, what stakeholders believe should be done and by whom, set the stage for next steps along the planning process, and provide insights about crafting public education efforts. The survey targeted state & federal agencies, academics, NGOs, private sector and industry groups, and the general public.

Second, NC Department of Environment and Natural Resources (DENR) will host a Science Forum in January 2010 to display the best available science on SLR for NC, and to announce projected sea level rise rates for North Carolina through 2100. The projected rates will be used as the scientific basis for policy and management. Scientists investigating SLR in North Carolina will be invited to make presentations about the rates and potential impacts. Target audience includes legislators, state and local policy makers and resource managers, elected

officials, emergency managers, planners, conservationists, private sector, and other interested parties.

Third, NCDCM plans to host a Policy Summit in the fall of 2010. The summit is intended to be a vehicle for collecting pertinent information needed for a Coastal Resources Commission (CRC) policy for addressing sea level rise. This will include gathering stakeholder input on response measures, conduct background information for Executive Branch action and establish a state-level clearinghouse for SLR information. CRC policy will form a solid basis for targeted amendments to use standards, regulations and Land Use Plan (LUP) guidelines. NCDCM may also present its own analysis of the types of policy responses that the CRC can consider. Once a draft policy is prepared the CRC will make it available for public input prior to becoming codified in the NC Administrative Code. A CRC sea level rise policy is necessary before the CRC and DCM can offer clear assistance to local governments, agencies, and other stakeholders.

Fourth, NCDCM will develop executive branch recommendations. The CRC's planning for sea level rise impacts will draw from a wide stakeholder base, but is not sufficient for the state's preparedness. North Carolina needs a coordinated, coast-wide adaptation strategy that crosses state agencies and levels of government. Using the input and recommendations gained via its own policymaking process, the Coastal Management Program will prepare a report to the NC Executive Branch to recommend actions that that Branch can take to direct and assist other agencies.

Fifth, after adopting a policy on preparing for sea level rise, the CRC will be better able to target changes to its regulatory program. Specifically, the Program can revise the 7B Land Use Planning Guidelines to help local governments incorporate specific policies, mitigation and adaptation tools. The CRC can also assess its other regulations and use standards for possible amendment, for example, in the areas of estuarine and oceanfront development standards.

Sixth, NCDCM will continue to work with local governments and partner agencies to provide support and advice on sea level rise adaptation planning and implementation. As a logical node agency for sea level rise response planning, NCDCM expects to serve as a source of technical information and expertise, and as a clearinghouse for information and resources. NCDCM will work through established channels such as Land Use Planning consultations with local governments, interagency meetings and working groups (e.g. the Coastal Habitat Protection Plan Steering Committee), as well as any new arrangements that may be established.

NCDCM's current management needs include:

- scientific consensus on relative sea level rise metrics for the state
- current assessment and description of impacts and evidence of sea level rise
- future risk assessments describing potential impacts on flooding & erosion; ecology & natural resources; social, economic & built environment
- public education support, including simple visualization tools for communication (maps, animations, etc)
- adaptation recommendations for the natural environment

Complementary Activities:

- *UNC-Wilmington survey of coastal residents (in process)*
- *APNEP Climate Ready Estuaries survey of local governments (beginning)*
- *APNEP listening sessions (complete)*
- *CRC Ocean Policy Study Committee Report (complete)*
- *EPA Climate Change Science Program Report (complete)*
- *DENR Interagency Leadership Team (ongoing)*
- *Duke University survey of local governments (complete)*
- *NC Beach & Inlet Management Plan (in process)*
- *NC Legislative Commission on Climate Change (ongoing)*
- *NCCF Beach Summit Report (complete)*
- *NCEM Risk Management Study (est. completion ~summer 2012)*
- *NOAA ecological modeling for SLR*
- *University Climate Change White Papers (complete)*

6) Use of Ecological Models for Coastal Habitat Restoration in Light of Climate Change

B. Boutin, the Nature Conservancy

Coastal habitat restoration is primarily driven by the desire to mitigate for location specific alterations to the ecosystem. Generally, this involves elimination of the primary threat(s) and re-establishment of vegetation, substrata, and/or associated ecosystem services. To ensure the sustainability of habitat restoration projects, resource managers must also consider future climactic conditions. Such considerations may result in the restoration of natural communities not present prior to degradation, but which provide similar or other desirable ecosystem services over the long-term.

As North Carolina is expected to experience significant climactic changes over the next century, there is a general need to model the expected outcomes to assist in the restoration of degraded coastal habitats. Modeling the effects of increased temperature regimes in the coastal plain can provide insight into potential vegetative alliance shifts. Resource managers can then utilize the output to identify potential invasions versus adaptive changes in vegetation, and, if appropriate, select the most suitable community to restore for long-term sustainability. Other models, such as those depicting increased storm frequency and sea-level rise, can help to identify locations most vulnerable erosion and inundation. One, identified resource managers can build adaptive capacity into the ecosystem to slow erosion and inundation, while allowing the natural communities to transition at a more natural pace.

Among the landscapes in North Carolina vulnerable to the effects of climate change, few are in as precarious a position as the Albemarle-Pamlico Peninsula. A rapidly rising sea threatens to forever change this complex ecosystem of estuaries, swamp forests, marshes and meandering rivers. Several recent studies have identified North Carolina's coast as one of the country's most vulnerable areas to climate change (Thieler and Hammar-Klose 1999; CIER 2008; Band and Salvesen 2009) and the effects are already visible on the Albemarle-Pamlico Peninsula: shoreline erosion is increasing, the region's peat soils are degrading quickly, and natural communities are

in hasty retreat from saltwater intrusion. As much as one million acres on the Peninsula may be lost to encroaching seas over the next one hundred years.

The Nature Conservancy, along with our partners, is working to bolster the Peninsula's adaptive capacity and mitigate the effects of climate change on the landscape. As part of the Albemarle-Pamlico Climate Change Adaptation Project, The Nature Conservancy and US Fish and Wildlife Service are planning and implementing a comprehensive set of strategies on the Alligator River National Wildlife Refuge to abate the effects of climate change on this rich complex of coastal ecosystems. The project will use land conservation, habitat restoration, and a variety of science-based adaptation techniques to ensure the sustainability of complex natural communities and valuable ecosystem services as the Albemarle-Pamlico Peninsula is inevitably transformed by changing climate and rising seas. Ecological models are an essential component of this project to ensure the success of on-the-ground restoration. Such models will help to identify priority erosion zones, predicted vegetation change, and effects of hydrologic restoration on the Dare County mainland.

7) Albemarle Pamlico NEP Planning for SLR

D. Carpenter Albemarle Pamlico National Estuary Program

The Albemarle-Pamlico National Estuary Program (APNEP) through its comprehensive mission and regional planning processes, stakeholder-driven (placed-based) goals and objectives, utilization of high-quality science, and vulnerable landscapes to climate change impacts can be a primary "evaluator" and "customer" for NOAA sea-level rise research products such as ecological forecasting models. APNEP is working with stakeholders to revise the program's strategic planning document, the Comprehensive Conservation Management Plan (CCMP). Staff envisions the new CCMP as incorporating principles of Ecosystem-Based Management (EBM) in order to forge more effective connections among humans, nature, science, and government. Ecosystem models such as the NOAA-sponsored products discussed at this workshop are essential EBM tools to provide stakeholders with an understanding of the net gains and losses in ecosystem services in the aftermath of climate change stressors such as sea-level rise.

To be most effective strategic ecosystem plans such as the CCMP should be integrated plans that address linkages among stressor-specific and resource-specific planning processes of various partners within the region. The role of regional ecosystem assessment in strategic planning is crucial: by synthesizing and integrating research products to evaluate whether planning goals and objectives on various planning horizons are being met, the assessment function supports adaptive management. Rather than simply being a retrospective exercise through the documentation of trend in and diagnosis of ecosystem changes, however, the greater value of assessment to decision makers is when the activity matures to one of being a prospective exercise of forecasting and proposing solutions and approaches. Soon rigorous sea-level rise forecast models will be invaluable, as climate change, along with changing land use dynamics, will be the initial stressor combination for ecological forecasts in the APNEP region.

Workshop Break Out Discussion 1: Summary of Researcher Capacities

The NOAA Coast Survey Development Lab's ADCIRC model predicts hydrodynamic circulation changes due to sea level rise. ADCIRC produces hypothetical and historical water levels, tides and storm surge. Through produced maps of predicted and observed water levels, the model can help determine areas of built and natural vulnerability and represent hypothetical circulation changes due to sea level rise. NOAA's VDATUM transformation tool can adjust coastal vertical datums to a common reference, thus allowing combinations of aquatic and terrestrial datasets. Through the achieved datum consistency, research and management tasks can be more successfully tackled.

The University of South Carolina Research MEM2 model predicts sediment accretion in marshes thus determining the critical depth of marshes above sea level for survival. MEM2 can answer the questions such as, at what point will the elevation of a marsh be beyond its tipping point and fated to become open water? What is the optimum sedimentation rate needed for marsh survival under the current sea level rise rate? USC research in NC has determined that the NC marsh sites studied occur at a relatively low elevation and are 'past the tipping point'. Thus MEM2 can determine marsh viability. Through the MEM2 model, maps can be developed indicating marsh status and vulnerability to drowning. The research has also determined that understanding and measuring wind tides is critical for vertical distribution and elevation of marshes in areas with small tidal range. The research also found that consideration should be given to using marsh fertilization as a management tool because increasing aboveground biomass will increase sedimentation. The MEM2 model can be used as reference for use by the Natural Resource Damage Assessment (NRDA). The MEMS2 highlights the need to determine possible areas for the transgression of marshes.

The Institute of Marine Science (IMS) Research Estuarine Simulation Model (ESM) can determine estuarine production under habitat-redistribution scenarios, material fluxes (i.e., C, N) on an annual scale, the relationship among trophic levels among various coastal habitats, shoreline stabilization on the structure and ecological function and a matrix of habitat specific estuarine production. The studied habitats include sub-tidal, SAV, inter-tidal flat, oyster, and marsh habitats. The EMS can produce maps of the location of future habitats under various sea level rise scenarios. IMS research has determined the importance of oyster productivity and the ecologic value and imperiled nature of intertidal habitats. IMS research can inform coastal zone management how climate change and various management decisions can impact habitat; the trade-offs of management decisions that affect near shore habitats; and impact analysis for restoration, damage assessment and ecosystem services.

The Neuse Landscape Model (NLM) can forecast and hind-cast coastal ecosystem response to sea level rise. NLM can predict vegetation response to various sea level rise scenarios thus forecasting habitat distribution and marsh persistence. NLM can produce maps and animations of habitat change and create opportunities to analyze management decisions prior to action. It is an experimental tool that allows manipulation of environmental parameters (i.e., water level, salinity, sediments).

The East Carolina University (ECU) estuarine shoreline dynamics tool predicts estuarine shoreline erosion with site specific erosion and land accretion rates. Through ECU research, it has been found that river trunk and tributaries respond to sea level rise differently with erosion rates relatively high along trunk and less erosion along tributaries. Marsh shoreline erosion rates are relatively low. The estuarine

shoreline dynamics tool can be used to map shoreline change rates and be developed into web products. The tools can inform managers of estuarine shoreline who make permitting decisions, help locate restoration sites and inform shoreline hardening regulations and rule making

The ECU estuarine shore-zone dynamics research can predict estuarine shore-zone position and character, showing the extent of shore-zone, defined as the area of the coast from the coastline to the upland boundary of regular flooding. ECU research has found that shore-zone increased in area over the last 50 years with vegetation patterns differing from hydrologic patterns. Therefore, vegetation is insufficient for defining shore-zone since it lags hydrology. The dynamics of shore-zone vary with position within estuarine and geomorphic position and are defined by its geomorphic position. Its evolution is linked to geomorphology. ECU work can be visualized with maps showing shore-zone change rates and a space for time analysis. This research can inform managers of estuarine shoreline (i.e., permitting decisions, locating restoration, and shoreline hardening regulations) and rule making. Land use decisions that accommodate transgression due to sea level rise and the impacts of erosion and sea level rise to ecosystem services can be informed by ECU research and tools.

Break Out Discussion 2: Management Requirements

During this workshop, managers identified a number of cases where decision making on resource mitigation strategies would be facilitated by a better predictive understanding of sea level rise scenarios and the consequences on ecosystem dynamics. There is a need to incorporate sea level rise into strategic planning for hazard protection, protection of valuable coastal habitats, and land use.

This planning requires a consensus rate of historic local sea level rise and updates as this rate changes. These rates are imperative to delineate inlet hazard zones and setback requirements. Managers see a need for better monitoring of sea level rise in the Sounds as well as in the estuaries.

In addition, Coastal Habitat Protection Plan (CHPP) and the designation of Strategic Habitat Areas (SHA) have common goals of long term habitat sustainability, which requires planning ahead for climate change and sea level rise.

Managers need prediction of future wetland loss as well as techniques to delay this loss and knowledge of where to acquire land to allow marsh migration. Where are wetlands accreting and where are they disappearing? Where will wetlands be stable and non-migratory?

Managers need estuarine erosion rates because erosion impacts coastal habitats and would be exacerbated by the increasing storminess and sea level rise predicted to occur with changing climate.

Managers need to understand the effects of varying bulkhead, sea walls and shore line stabilization techniques on near shore and shore-zone habitat. Where are shorelines especially unstable?

They need better elevation data including vertical to horizontal slope to better predict habitat migration patterns.

Managers need to understand the changes in salinity expected with sea level rise, and how nursery areas will be affected.

Decisions need to reflect more of a process response, reflecting an understanding of the physical processes that drive shoreline change. Sustaining North Carolina beaches for recreation requires sources of sand for beach nourishment. What are the habitat effects of this nourishment on the beaches as well in the off-shore sand source areas? Is there a beneficial use of dredge spoil to aid habitats in keeping up with sea level rise?

Managers see ecological models as a great resource for successful monitoring of change, providing a role in education and environmental advocacy. However, models can present a challenge due to differing scales. They want to understand and be clearly told the model limitations and plenty of model verification.

The Breakout Group assembled a list of relevant questions that can be aided by the NC SLR Project research or may provide ideas for future research. The following are information needs identified by the Breakout group, and some responses from NC SLR Project PIs or their colleagues in italics. Further information relating NC SLR results and tools to these issues was addressed in the All Hands Session – see “All Hands Discussion” on p. 27.

Manager Information Needs

1. What is rate of SLR in North Carolina?

Ben Horton, University of Pennsylvania, the absolute rate of relative sea-level rise in North Carolina during the 20th century was 3.0-3.3 mm/yr, which began at the end of the 19th century and is broadly synchronous with other studies on the Atlantic coast. Dr Horton provided records of relative sea level rise from two salt marshes in NC since AD 1500 to complement existing tide gauge records and to determine when recent rates of rapid sea-level rise commenced. Reconstructions were developed using foraminifera-based transfer functions and composite chronologies that were validated against regional 20th century tide-gauge records.

Chris Zervas is an oceanographer with NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS), which has been measuring sea level for over 150 years, with tide stations operating on all U.S. coasts through the National Water Level Observation Network. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 128 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of high frequency phenomena, such as waves and tides, to compute an accurate linear sea level trend.

Station Name	First Year	Year Range	For all data to 2006	
			MSL Trend	+/- 95% Confidence

			<i>Interval</i>	
<i>Sewells Point, VA</i>	<i>1927</i>	<i>80</i>	<i>4.44</i>	<i>0.27</i>
<i>Portsmouth, VA</i>	<i>1935</i>	<i>53</i>	<i>3.76</i>	<i>0.45</i>
<i>Chesapeake Bay Bridge Tunnel, VA</i>	<i>1975</i>	<i>32</i>	<i>6.05</i>	<i>1.14</i>
<i>Oregon Inlet Marina, NC</i>	<i>1977</i>	<i>30</i>	<i>2.82</i>	<i>1.76</i>
<i>Beaufort, NC</i>	<i>1953</i>	<i>54</i>	<i>2.57</i>	<i>0.44</i>
<i>Wilmington, NC</i>	<i>1935</i>	<i>72</i>	<i>2.07</i>	<i>0.40</i>
<i>Southport, NC</i>	<i>1933</i>	<i>74</i>	<i>2.08</i>	<i>0.46</i>
<i>Springmaid Pier, SC</i>	<i>1957</i>	<i>50</i>	<i>4.09</i>	<i>0.76</i>
<i>Charleston, SC</i>	<i>1921</i>	<i>86</i>	<i>3.15</i>	<i>0.25</i>

2. Are marshes accreting or disappearing? What wetlands are stable, migratory and non-migratory?
3. The gap between good research and decision making is a major obstacle. We recommend that granting agencies ensure that research is translated into an easy to understand format for policy makers.
4. Consensus is needed on the future sea level rise probability curve. If relative sea level rise differs dramatically in different areas of the state, we need to address the high risk zone.
5. We need some benchmark for doing risk assessment, guidance based on science. The assessment goals should include adaptive management to ensure inclusion of new information.
6. Estuarine erosion rates are needed as well as delineation of shoreline in order to quantify rates of erosion. Through this, we need to map shoreline rates, and shoreline stabilization structures. And the location of stable and unstable shoreline.

Erosion rates are available from Reide Corbett (East Carolina University) for the Neuse River. Of the 156 km of shoreline analyzed, 93.0% eroded, 6.6% accreted, and 0.4% did not change. The average Shoreline Change Rate was -0.58 m yr^{-1} and ranged from -3.48 to 2.89 m yr^{-1} . Higher erosion rates were determined down-estuary.

7. Vertical elevation information is needed in an easy to use format. Vertical to horizontal slope information will ensure knowledge needed for habitat migration routes and important for determination of the feasibility of habitat migrations.
8. Knowledge is needed about salinity changes due to sea level rise, to ensure ability to forecast habitats and migrating species. Monitoring of salinity is needed.

Key Product Needs:

1. Incremental predictions of wetland loss including fresh water, tidal and coastal marshes, and pocosin forests. Long-term preservation of these habitats is desirable.
2. We need maps to include area from the coastline to the upland boundary of regular flooding. We need to extend upland in order to save areas from development and leave room for habitat migration.

Mark Brinson (ECU) has been researching the 'Space for Time' concept that will help managers to determine where protecting land from development and leaving room for migration is a goal. The spatial data collected during the NOAA sea level rise project for the Neuse River may provide managers some help and can be applied to a temporal context using a space-for-time substitution. At the earliest stages, low headward slope facilitates rapid upstream migration in river valleys, apparent mostly in the inner estuary. In the intermediate stage, steep valley walls constrain lateral migration as shoreline erosion reduces the extent of shorezone. This is apparent through the middle estuary where shorezone is much less extensive. In the late stage, low lateral slope of the interstream divide facilitates over flat migration. This stage occurs in the outer estuary. And lastly, terminal non-migration occurs only after the entire landscape has become inundated. There is not adjacent land available for migration. The fate of shore-zone is entirely controlled by erosion and accretion in this stage.

3. Models are only the first step. An interface must be developed to make the models available to policy makers in a format that is easy to use and provides communication of research results through visualization, geospatial tools and maps. These interfaces should be designed in collaboration with users! The visualization, geospatial tools and mapping representation should be designed to inform environmental managers, fisheries managers (SHPP and SHA), Coastal Resource Commission, the Coastal Hazard Science Panel and other policy entities. Such tools are consensus builders on issues in which policy makers must act.

*Charles "Pete" Peterson emphasized the **need for a scientific council** to derive consensus of science and give credibility.*

4. Role of models accentuated by visualization, geospatial tools and mapping representation:
 1. Education role, advocacy role, litigation role;
 2. Good for monitoring and testing the effects of various management strategies;
 3. Models must include a process response and consider the physical processes that drive shoreline changes;
 4. The modeling challenge is to be able to give results in a spatial and temporal scale appropriate for decision making. The models **MUST BE** calibrated and verifiable. The use of hind casts is valuable in convincing users that the results are an adequate representation of the future thus avoiding controversy. The users must be aware of the model limitations and the difference between the model process and the real

response of environmental change and management activities. Error estimates are important.

5. Models are essential in some regulatory capacities such as reducing nutrient loading, TMDL and storm water pollution.

All Hands Discussion

On Day 2 of the Workshop, managers and researchers interacted to determine how the NC SLR Project models can be used to answer management needs discussed in the Management Breakout group. The needs are listed below, followed by NC SLR Project relevant knowledge or tools in italics.

1. Regional rate of relative sea level rise (RSLR) is needed including a 100 year trend and expectations for the future based on global climate change models. This information is imperative as a benchmark for management analysis. The management decisions linked to this rate include forecasting habitat switching and habitat evolution, assessment of mitigation success and planning for restoration projects. This information will also help establish inlet hazard zones, construction setbacks, peat degradation rates, groundwater availability and quality, and general vulnerability of coastal areas*.

NC SLR Project models that address these issues: The Neuse Landscape Model, the (ADCIRC Model, the Shoreline change research and the MEM2 Model give environmental answers related to RSLR. Dr. Morris recommends a conservative approach, using the 100 year trend and from this trend determine an acceleration rate.

**(Note world wide sea level rise predictions: In its 2007 report, the Intergovernmental Panel on Climate Change (IPCC) forecast a sea level rise of between 19 and 59 centimeters by 2100 using various carbon dioxide emission scenarios. The IPCC forecast excluded "future rapid dynamical changes in ice flow" and stated "Larger rises cannot be excluded but understanding of these effects is too limited to assess their likelihood,". Research continues. The Copenhagen Synthesis Report recently concluded that "The updated estimates of the future global mean sea level rise are about double the IPCC projections from 2007".*

2. The National Marine Fisheries Service needs information on estuarine habitat status for estuarine dependent species. Knowledge of the current and future health of spawning and nursery areas is important in managing commercial and recreational important fisheries.

NC SLR Project models that address these issues: The IMS Habitat Simulation Model and the Meta Analyses of trophic assessment of connectivity of estuarine habitats.

3. Assessment of the quality and quantity of sand resources is needed for beach nourishment projects.
4. Knowledge of the fate of the Outer Banks Barrier Islands is needed. Loss of the barrier islands will change the character of the coast of NC.

NC SLR Project models that address these issues: the Neuse Landscape Model, and the ADCIRC Model.

5. Maps and tools indicating marsh migration potential under various sea level rise scenarios.

NC SLR Project models that address these issues: The Neuse Landscape Model and the MEM2.

6. Salinity change maps

NC SLR Project models that address these issues: the Neuse Landscape Model, the ADCIRC Model, and IMS Habitat Simulation Model

7. How will estuarine and coastal productivity change in response to RSLR? What are the indicators that can document these changes? Dean Carpenter from APNEP has information available on indicators.

NC SLR Project models that address these issues: the Neuse Landscape Model, the ADCIRC Model, and IMS Habitat Simulation Model

8. Restoration guidelines to ensure restoration success with RSLR for all estuarine habitats.

NC SLR Project models that address these issues: the Neuse Landscape Model, MEM2 ,ADCIRC Model, and IMS Habitat Simulation Model

9. How will RSLR impact future stock assessments and productivity? Mapping needed of habitat location under various RSLR scenarios.

NC SLR Project models that address these issues: The IMS Habitat Simulation Model, ECU shorezone change, Space for time assessment.

10. Infrastructure impacts; storm hazards planning and response. How will habitat loss affect flooding?

NC SLR Project models that address these issues: the Coastal Flooding (ADCIRC) Model with extrapolation

11. There needs to be a comprehensive inventory of habitat assets and their value. CHPP is a great beginning!

NC SLR Project models that address these issues: The IMS Habitat Simulation Model, ECU shorezone change

12. Social science research to ascertain the social and economic risks of RSLR.

13. Identifying and quantifying ecosystem services at finer spatial scales, higher resolution and with geo-referencing.

14. Better marsh elevation information including more SETS. Better resolution of marshes with LIDAR (Carolyn Currin of NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) in Beaufort, NC is working on this).

15. Better tide data including permanent stations in Albemarle, Pamlico and Currituck Sounds.
16. Saltwater intrusion forecasts.
17. All NC SLR Project modeling results into GIS format and use of other visualization tools to communicate results more effectively.

Research to Application; the next step

Managers have been a valuable partner during the entire process of the NC SLR Project. Both Guy Stefanski (Strategic Planning Manager, NCDCM) and Mike Street (Department of Marine Fisheries) were involved in the program planning and they and numerous other NC state managers have attended several meetings of investigators as the research progressed. The research results are already being used by NC decision makers. Examples of this connection include:

- ECU provided both erosion and accretion rates using historical and recent aerial photography to Scott Chappell writing the 2010 update of the state's Coastal Habitat Protection Plan, thus potentially helping in selection of shoreline stabilization methods that benefit both the property owner and the ecosystem;
- IMS collaborated with state resource managers on salt and freshwater marsh habitat research that demonstrated the connectivity of wetlands to near shore habitats on ecosystem health. This scientific demonstration resulted in modification of the permit process for bulkheads in tidal estuaries and rivers in the 20 coastal counties under the North Carolina Division of Coastal Management and will allow access to the marsh by aquatic fishes and crustaceans, and prevents any new bulkheads water-ward of the marsh. Prior to this change, bulkheads were permitted up to five feet water-ward from a marsh, thus isolating the marsh from fish and other aquatic animals that use wetlands during part of their lifecycle;
- The habitat productivity ratios presented in the IMS (Peterson) synthesis paper based on "Habitat Equivalency" have now been adopted by the NOAA Restoration Office in determining the quantitative amount of compensatory restoration of salt marsh, oyster reef, or SAV habitat required of responsible agencies.

Workshop discussions defined various barriers that impede the use of NC SLR Project research results in management decision-making. A summary of management needs identified in this workshop and possible scientific response to such needs are listed below:

Management Need

Science Response

<p>What is the current rate of relative SLR in the various regions of NC? What should we plan for in the future?</p>	<p>Current rates available from NOAA tide gauges. Establishment of a NC Scientific Council on Climate Change impacts on shoreline change and coastal habitats. This council will need to establish consensus on future probability curve; updated as information improves</p>
<p>Incremental predications of wetland stability of marshes in the Pamlico Sound. Location of migrating wetlands and non-migratory wetlands. Incremental predications of wetland stability of marshes on the Neuse River.</p>	<p>Information from SC MEM2 model for the Pamlico Sound developed into a geospatial tool/mapping product. The ECU Shore zone dynamic research on Neuse River into a geospatial tool/mapping product. Various relative SLR scenarios developed for both models using spatial and temporal scales established by a panel of managers.</p>
<p>Map estuarine shoreline with indication of stabilization structures. Erosion rates of state estuarine shorelines. Location of stable and unstable shorelines. Map should include entire shorezone to include the ability to buy land for potential habitat migration.</p>	<p>ECU Shoreline dynamic tool now available for the Neuse River. Tool should be tested and improved by a group of users. Similar shoreline analysis used by ECU should be conducted for estuarine areas of all of NC. The analysis should include stabilization structures.</p>
<p>Vertical elevation information is needed in an easy to use format. Vertical to horizontal slope information.</p>	<p>Improve vertical resolution through GPS connection to vertical control stations to show precise Orthometric Heights. VDATUM for entire NC coast to ensure single datum from underwater topography to land topography. Improve LIDAR measurement of wetland elevations.</p>
<p>Salinity changes due to SLR , both ground water and estuarine, for decision making for strategic habitat planning and agriculture.</p>	<p>Model needs to be developed for salt wedge dynamic under various RSLR scenarios.</p>
<p>Landscape type model with multiple parameters including biology, geology, salinity, river flow/run-off, temperature and sedimentation with environmental feedback mechanisms to accurately predict the fate of coastal habitats under various relative SLR scenarios. Visualization, geospatial tools and mapping representation should be developed from this large model to answer specific management questions from fisheries, hazards, and coastal resources sectors. This model will thus allow analysis of</p>	<p>Neuse Landscape Model (Reyes) or a similar state of the art sediment and process model is a good start to this requirement. This model should be integrated with the MEM2 for more accuracy in sediment accretion. This model should be expanded to include the entire NC coast and improved as data become available, including improved resolution through river flow information from increased stream gauges, sediment elevation tables and better vertical resolution (better LIDAR?) to enable local land use decisions. The model</p>

<p>management decisions prior to action. It will be an experimental tool that allows manipulation of environmental parameters and thus become a consensus builder.</p>	<p>should be improved for communication ease with various interfaces thus allowing visualization, geospatial tools and mapping representation. Sea Grant or other management training agencies should be intimately involved in the testing and development of these visualizations, geospatial tools and mapping representations, using management workshop and other management involvement in development.</p>
<p>Current and future information on estuarine habitat status for estuarine dependent species is needed by Marine Fisheries to manage fisheries. Knowledge of the effects of various shoreline stabilization techniques on nearby near shore and adjoining property.</p>	<p>The IMS Habitat simulation model – or similar model including the productivity effect of shore line stabilization comparison where needed - should be extended to include the entire estuarine coast of NC. The model should be improved for communication ease with various interfaces thus allowing visualization, geospatial tools and mapping representation.</p>
<p>Knowledge of the fate of the barrier Islands under various relative SLR scenarios.</p>	<p>NLM has a simple sediment transport model and is a good starting place for visualization, mapping and reference. Improvements are needed in sediment transport modeling for the NC barrier islands. The model development should include various interfaces thus allowing visualization, geospatial tools and mapping representation.</p>
<p>Assessment of the quality and quantity of sand resources is needed for beach nourishment projects.</p>	<p>Research is needed and model/geospatial tools developed to provide scientific clarity on this question.</p>
<p>Restoration guidelines to ensure restoration success with relative SLR for all estuarine habitats.</p>	<p>Habitat equivalency values established through research and data mining of all NC coastal habitats – similar to work done by IMS.</p>
<p>Infrastructure impacts; storm hazards planning and response. How will habitat loss affect flooding?</p>	<p>ADCIRC model currently available through NOAA work or through current FEMA funding should be improved for communication ease with various interfaces thus allowing visualization, geospatial tools and mapping representation.</p>

What are the social and economic risks of RSLR?	Social science research needed.

Conclusions

Transition of research results to application is critical for adaptive management to prepare for climate related sea level rise and storminess. CSCOR included management objectives throughout the planning for the EESLR program in North Carolina. This White Paper presents several ways that application of NC SLR Project results and tools can meet NC state managers' needs. The Breakout Group results demonstrate a clear need for better visualization, geospatial tools and mapping representation, developed through the involvement of potential users. After the development is complete, manager training workshops are needed (e.g. the NERR Coastal Training Team, Sea Grant, or another group with this expertise).

Adaptive management for sea level rise and storminess require quantitative predictive models of ecosystem responses that are periodically validated for accuracy and updated through monitoring and model advancements. This requires a collaborative approach between users and researchers. In addition, funding agencies should incorporate management needs and input throughout the study period and establish transition to application mechanisms as a prerequisite to project support. Such calls for proposals should ensure that funded scientists adapt their work to address practical needs while still advancing important research questions.

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