

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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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

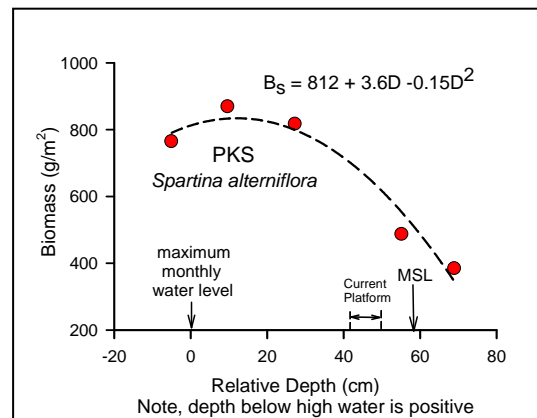


Figure 1 Biomass density of *Spartina alterniflora* grown at different relative elevations within the intertidal zone. Elevation is shown as depth below the mean maximum monthly water level at the site.

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.

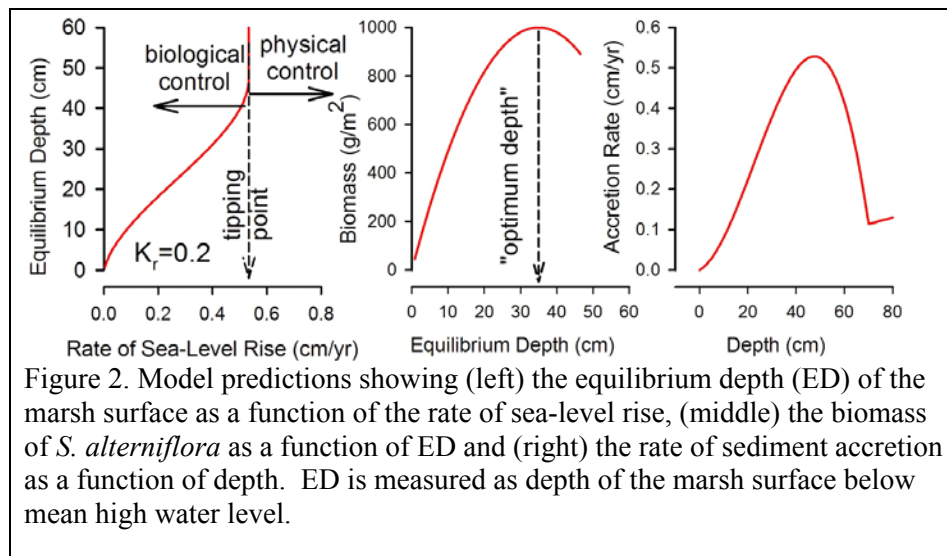


Figure 2. Model predictions showing (left) the equilibrium depth (ED) of the marsh surface as a function of the rate of sea-level rise, (middle) the biomass of *S. alterniflora* as a function of ED and (right) the rate of sediment accretion as a function of depth. ED is measured as depth of the marsh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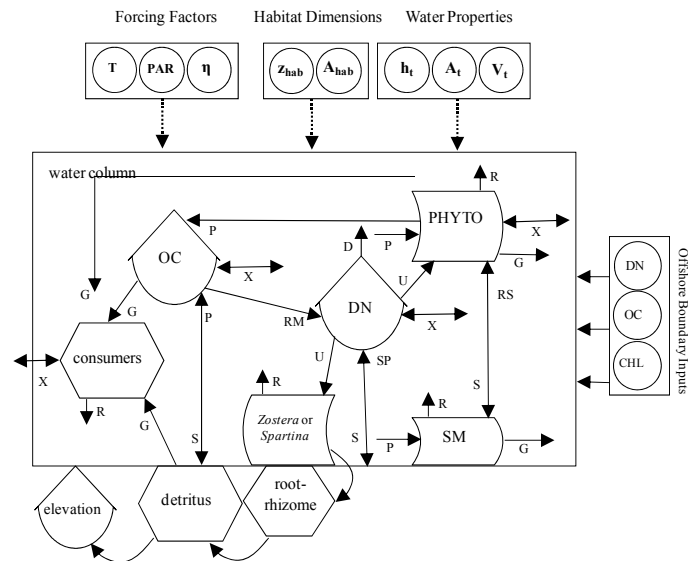
Focus of Research

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).

Research to Applications Task Force of the Ocean Research and Resources Advisory Panel. 2007. Best Practices for Increasing the Impact of Research Investments. 19 p.

Thieler, E.R., and E.S. Hammar-Klose. 1999. National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast. U.S. Geological Survey, Open-File Report 99-593.

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