Context:

Research by Virginia Coast Reserve Long-term Ecological Research project (VCR/LTER) scientists continues to focus on our core hypothesis that ecosystem, landscape and land use patterns within terrestrial-marine watersheds are controlled by the vertical positions of the land, sea and freshwater groundwater table surfaces. Coastal storms, climate change, long-term eustatic sea-level rise and land subsidence cause variations in the elevations of these surfaces that drive ecosystem dynamics. Ecological processes, including organic matter production, species extinction and colonization, alter the rates of erosion and sediment deposition and thereby alter land and water table surface elevations. Short-term episodic events and long-term systematic trends in sea level and land and and groundwater surfaces give rise to variations in nutrient availability, primary productivity, organic matter accumulation and trophic interactions.

In VCR/LTER I (1997-1992) we focused on geophysical controls (e.g., storms) on coastal ecosystems. In VCR/LTER II (1992-1994) we introduced the concept of ecological state change, which was linked in VCR/LTER III (1994-2000) to relationships between free surfaces (land, sea, freshwater table). Under the current VCR/LTER grant (VCR/LTER IV 2000-2006), we have added a hypsometric perspective, which provides an alternate way of examining ecological patterns on the coastal landscape.

Activities:

Continuation of ongoing experiments, monitoring and measurement programs comprise the bulk of our activities for the year. These activities are necessary to provide the long-term perspective required of LTER sites. These core activities include tracking of changes in ecological states, the collection of meteorological, ground-water level and tidal data, monitoring a transect of water chemistry stations, monitoring of terrestrial vertebrate populations (birds, mammals), measuring the effect of the manipulation of marsh water levels, tracking changes in marsh surfaces relative to sea- level rise and improving our knowledge of transport processes within the lagoon.

Hurricane Isabel on Sept. 17, 2003 caused extensive flooding on the barrier islands and on the mainland. For our principal island research sites on Hog Island, the effects of storm surge were relatively mild, with little erosion on the island beaches. Effects on vegetation were also relatively modest, with only a few shrubs at the seaside edges of thickets killed by salt spray. However, on islands more low-lying than Hog Island, the effects of both bayside flooding and waves were more profound, with major erosion on Myrtle and Ship Shoal Islands. In Phillips Creek Marsh, as much as 2.1 cm of sediment was deposited on the marsh surface by the hurricane confirming the importance of periodic disturbance to maintenance of marsh elevation with respect to sea level. Although its relationship to Hurricane Isabel is not entirely clear, we have also observed die off of a large area of grasses in our Phillips Creek Marsh study area.

Flooding on southern Hog Island during Hurricane Isabel. The first image is from high tide on the previous day. The second image is from near the peak of flooding during Isabel. Web-cameras on both northern and southern Hog Island used our wireless network link to the islands to send live images to researchers at the LTER All-Scientists Meeting in Seattle throughout the storm. The system remained operational throughout the storm, until backup power at the laboratory finally ran out.

Upland:

Our activities in the upland have focused on better understanding the relationship between ground-water and land-surface free surfaces, and how this relationship affects ecological processes including productivity, decomposition. We continued our efforts, to integrate data on meteorology with our records of primary productivity. This has led to preparation of a new heuristic model that relates productivity to a wide array of physical and biotic processes. We have also been engaged in studying the trophic structures related to gulls and colonial waterbirds. Specific activities include:

1. Special surveys of the small mammal faunas of low-lying barrier islands were conducted in November of 2003 and March and June of 2004 (Porter, Moncrief and collaborator Dueser). Chimney-pole Marsh, Ship Shoal Island and Myrtle Island are very low lying, with maximum elevations < 3 m.

2. Intrasite (VCR) synthesis activities continued to examine interannual productivity patterns in relation to meteorological and climatological variables. (Christian, Day, Blum, Young, Brinson, Mills, McGlathery, Zieman, Hayden and Porter). This ongoing effort started with developing a database of meteorological and climatological data that combines LTER meteorological station data with external data that predates the initiation of the VCR/LTER site. Data on productivity and indicators of productivity (e.g., biomass, stem counts) were compiled for *Myrica cerifera, Spartina patens, Spartina alternaflora*, and *Distichlus spicata*. The research group held meetings in July 2002, October 2002, May 2003, and May 2004 to work on analyses of this data, focusing on within-site and within-species relationships between production and climatological variables. This effort has resulted in a new heuristic model for understanding the relationship between primary productivity and physical and biological drivers.

3. Continued monitoring of permanent vegetation plots and groundwater wells on Hog Island. Brett McMillan, a doctoral student is focusing his dissertation work on vegetation dynamics on "pimples" (small dunes with highly zonated vegetation surrounded marshes). Attempts to utilize ground penetrating radar to map groundwater levels and root architecture and biomass will be initiated. (Day);

4. The Virginia barrier islands historically have been among the most important nesting areas for colonial and beach-nesting waterbirds in the entire mid-Atlantic region. The apparent spread of the raccoon (*Procyon lotor*) and the introduced red fox (*Vulpes vulpes*) on these islands has significantly reduced habitat suitability for these avian species. Collaborator Raymond Dueser and PI Nancy Moncrief are conducting studies designed to produce a strategic plan for restoring avian habitat through predation management. This has included periodic track surveys to estimate densities, radiotracking of individual predators to determine movement patterns (especially inter-island movements) and nest predation experiments using real and simulated (clay) eggs. (Moncrief, Dueser, Porter);

5. Preliminary examination of disease status of island small mammals was instigated in association with UVA veterarian Sandy Feldman. Fecal and blood samples were collected and analyzed using genetic and antibody assays (Porter, Moncrief, Dueser);

6. Declassified satellite imagery was used to examine landscape change since 1963 on Hog Island and Phillips Creek research sites (Porter, Hayden, Young). Change analyses have been used to document shrinking of marsh surfaces on Hog Island and to determine the topographic ranges colonized by shrubs. This imagery was obtained with the help of John Vande Castle at the LTER Network Office and Scott Collins at the National Science Foundation. It has been supplemented with Thematic Mapper and IKONOS imagery from collaborators Chris Justice (UMD) and Chip Bachmann (NRL).

7. In the area of cross site studies, we have continued work at the Florida Coastal Everglades and Sevilleta LTER sites aimed at understanding the relationship between vegetation hydrocarbon emissions and climate controls (Hayden). We also continued work at a combination of nine LTERs and other long-term research sites where we are examining the relative importance of the organic matter source versus environmental conditions on the microbial community structure and decomposition (Blum, Mills).

8. Continued long term measurements of shrub and herbaceous productivity on fertilized and unfertilized plots on Hog Island. (Day, Young)

9. Initiated studies examining the effects of wildfire on Parramore Island (Young)

10. Precipitation sampling station is being reestablished at a new location (Oyster VA) following destruction of the previous station by flooding during Hurricane Isabel. (Galloway)

11. 13. Continued monitoring of bird populations as a member of the Virginia Barrier Island Avian Partnership. Monitoring of gull-billed tern populations in conjunction with U.S.G.S./B.R.D. (Erwin)

Lagoon:

We continue our focus on the linkages between watersheds in the VCR landscape and the coastal lagoons. Watersheds have been delineated on the Delmarva Peninsula that vary in the proportion of land area representing agriculture, urban or forest land use. Atmospheric deposition and groundwater discharge provide the major external nutrient inputs to the systems. Our studies relate nutrient inputs to processing by primary producers and heterotrophs within the lagoon in order to assess the fate and transport of nutrients across the landscape. This assessment requires linking the biological drivers with physical drivers (wind, tides) in a coupled hydrodynamic-ecological model of the bay. Our models of hydrodynamics and sediment resuspension have paved the way for a large-scale recolonization effort of the keystone species, *Zostera marina* (eelgrass), in the VCR lagoons. Specific research activities in the lagoon include:

1. Augmented the long-term water quality monitoring program for the VCR coastal lagoons by adding a second mainland ñ ocean transect. We now have transects that represent the gradient from mainland creeks ñ mid-lagoon shoal ñ barrier island ñ ocean from two bays with different watershed land use and nutrient loading rates. We couple measurements of water quality parameters with estimates of primary producer (phytoplankton, benthic algae) biomass throughout the lagoon complex (Blum, Christian, McGlathery, Anderson).

2. Continued study of the role of land use in affecting groundwater quality (base flow) in 14 tributaries to coastal lagoons in the VCR. We now have data sets that span both wet and dry years. These data are used to estimate groundwater nutrient loading to Hog Island Bay. (Mills, Anderson)

3. Evaluated the impact of watershed land use on biodiversity of benthic invertebrates in coastal plain tidal creeks, with the goal of developing a biotic indicator of water quality. (McGlathery, Zieman)

4. Conducted detailed studies of groundwater movement and transformations through the riparian zone in Cobb Mill Creek, located adjacent to the new Anheuser Busch Coastal Research Center (Mills).

5. Continued study of nitrogen transformations (nitrogen fixation, mineralization, nitrification, denitrification in the water column and sediments of Hog Island Bay. This information will allow us to determine the fate of nitrogen inputs to the bay and the role of primary producers in determining that fate. (Anderson, McGlathery)

6. Initiated collaborative research with Pier Luigi Viaroli (University of Parma, Italy) on network analysis of nutrient cycling and metabolism in coastal lagoons (Christian, McGlathery, Anderson)

7. Continued development of hydrodynamic model to determine variable residence times in Hog Island Bay. This model will be coupled with information on biological transformations (see above) to determine the fate and transport of nutrients in Hog Island Bay (McGlathery, Anderson, Wiberg with collaborator Friedrichs (VIMS))

8. Deployed a profiling Doppler current meter and wave height measurement system to assess current flows at a second site in Hog Island Bay. These data will be used to validate the hydrodynamic model of the lagoon. (Wiberg)

9. Continued studies of surface and subsurface circulation in Hog Island Bay using sequential global positioning system locations of ì driftersî to validate hydrodynamic model. (Oertel, Anderson, McGlathery in collaboration with Jay Austin (ODU))

10. Continued measurements of sediment resuspension and light attenuation in Hog Island Bay. A model of sediment resuspension and its relationship to light attenuation in the water column has been constructed that will guide our efforts in reintroducing eelgrass colonization to Hog Island Bay. (Wiberg, McGlathery)

11. Initiated efforts to reestablish eelgrass, which historically has been the keystone species in the VCR lagoons. Recolonization is achieved by casting seeds in areas known to have conditions suitable to support eelgrass growth and survival (see above). (McGlathery, in collaboration with Robert Orth (VIMS)).

12. Continued analysis of biotic and abiotic factors influencing macroalgal distribution and ecological performance, with special emphasis on the invasive species *Codium fragile* (McGlathery)

13. Evaluated the trophic interactions between macroalgae and benthic fauna. Determined the impact of macroalgal blooms on diversity and abundance of benthic infauna and epifauna and the extent to which grazing modulates the response of macroalgae to nutrient enrichment. (McGlathery)

14. Continued studies of the role of benthic microalgae in influencing the fate of nitrogen in coastal bays using stable isotope tracer techniques. (Anderson, McGlathery, with collaborator Liz Canuel (VIMS))

15. Continued research on the use of macroalgae as bioindicators of nutrient enrichment from agricultural watersheds to Hog Island Bay. (McGlathery)

16. Doctoral student Michael Lowit continued work on the analysis of the spatial and temporal distribution of microbial communities in Machipongo (seaside) and Nassawadox (Chesapeake Bay) tidal creeks. (Blum)

17. Deposition fluxes of atmospheric N via wet and dry pathways are significant nutrient sources for N-limited coastal ecosystems. To quantify these nutrient sources, precipitation was sampled weekly through spring 2003 and analyzed for major chemical constituents (SO_4^{2-}, $CH_3SO_3^-$, Cl^-, NO_3^-, NH_4^+, H^+, Ca^{2+}, Mg^{2+}, Na^+, and K^+). During late spring and summer 2003, intermittent equipment problems limited the frequency of collections and the reliability of resulting samples. In September, a hurricane seriously damaged the field equipment and associated infrastructure forcing suspension of routine operations. We took this opportunity to move the site to the newly established meteorological station and to re-build the sampling equipment. Routine operations at the new station resumed in early summer 2004. (Galloway)

18. Developed a nutrient budget for Hog Island Bay, relating nitrogen inputs from allochthonous sources (groundwater, atmospheric deposition) and autochthonous sources (mineralization, nitrogen fixation) to nitrogen sinks (assimilation by primary producers, denitrification). (Anderson, McGlathery)

19. Continued measurements using a digital fathometer integrated with global positioning system measurements to extend our bathymetric mapping to include lagoon inland of Smith Island (Oertel)

Marsh:

Marshes represent the biomes most susceptible to state changes driven by changes in sea level. For this reason we have focused on understanding the relationship of marsh surfaces to sea level rise and the role that biology may play in the response of marshes to that rise. Of particular interest this year is the investigation of large marsh patches which supported only dead vegetation this year.

Specific research activities this year included:

1. Investigation of patches of dead vegetation occurring in Phillips Creek Marsh. This is similar to what has been seen in LA, SC, and GA. This includes initial sampling and characterization of the event, comparisons of the patterns of mortality in comparison with other marsh systems, and determination of the mode of mortality. (Christian, Blum)

2. Continued long-term studies of effects of sea-level change and disturbance on salt marshes. This work included continuation of pumping experiment, elevation measurements, plant biomass studies at multiple marshes, monitoring vegetation in permanent plots, and organic matter accumulation. Also continued network analysis studies. (Christian, Blum, Brinson)

3. Development of global scale observing system for land-based activities as part of GTOS. (Christian)

4. Doctoral student Bo Dame is using marsh ponds as focal ecosystems for food web networks. (Christian)

5. Continued work on spatial and the temporal variation in bacterial communities in response to environmental gradients. (Blum)

6. Continued work on the contribution of organic matter dynamics to salt marsh landscape patterns. (Blum)

7. Masters student, Pat Willis, continued work to determine the role of organic matter accumulation in marsh surface accretion processes at a variety of temporal scales. (Blum, Wiberg)

8. Doctoral student Cassondra Thomas completed work on biogeochemistry and organic matter accumulation in salt marsh sediments. (Blum)

9. Undergraduate student, Gina Casciano, completed work on the temporal effects on microbial community development and composition in decaying salt marsh plant litter. (Blum)

10. Doctoral student Amanda Floyd began experiments focusing on the relationship between scales of plant species and microbial community structure variation in salt marsh sediments. (Blum)

11. Continued studies of the distribution and growth of *Salicornia virginica* in relation to sediment chemistry (NH_4^+, PO_4^{3-}, H_2S, salinity, pH, organic content, Eh, total nitrogen and phosphorus) on mainland and island marshes. (Zieman)

12. Continued studies of the impact of grazing insects on the salt marsh cord grass *Spartina alterniflora* on island and mainland marshes leading to a M.S. Thesis by graduate student Nicola McGroff. (Zieman)

13. Continued work on the impact of fiddler crab (*Uca pugnax*) burrows on pore water chemistry of a *Spartina alterniflora* marsh on Hog Island. (Zieman)

14. Continued monitoring and data management of shallow groundwater wells in upland margin of upper Phillips Creek, showing rising trends in specific conductance since the mid 1990's. (Brinson)